# PERFORMANCE EVALUATION OF ADVANCED ANAEROBIC REACTORS FOR REDUCING HRT

*by*

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# CERTIFICATE

This is to certify that the work entitled "PERFORMANCE EVALUATION OF ADVANCED ANAEROBIC REACTORS FOR REDUCING HRT" has been carried out by MR. SHISHU PAL SINGH under our supervision and has not been submitted elsewhere for the award of a degree.

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*Shishu Pal Singh*

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# NOMENCLATURE

| | |
|---|---|
| a | Volume of Ferrous Ammonium Sulfate required in titration with blanksolution (distilled water) |
| b | Volume of Ferrous Ammonium Sulfate required in titration with diluted sample |
| C | Capacity of the Reactor |
| HRT | Hydraulic retention time |
| N | Normality of Ferrous Ammonium Sulphate |
| $(VS)_i$ | Volatile Solids in influent slurry |
| (VS)e | Volatile Solids in effluent slurry |
| $V_i$ | Volume of daily influent slurry |
| $V_e$ | Volume of daily effluent slurry |
| x | Mass of 5 ml sample dried at $104^oC$ |
| y | Mass of 5 ml sample ignited at $550^oC$ |

# ABSTRACT

An effort has been made here to evaluate the performance of anaerobic reactors, some of them with different inert media immersed in the slurry under controlled conditions with the objective of increasing the gas yield by providing enhanced surface area for the attachment of the microbes. The experiments were conducted for two different values of hydraulic retention time which refers to the volume of the digester per unit feed rate. The measurements were made for the gas yield, volatile solids and chemical oxygen demand.

A comparison of the various biogas plant designs reviewed here shows that even for a small capacity plant, the HRT is pretty large which increases the digester volume and makes the plant much too expensive for a common man in the villages. The provision of additional surface area increases the microbial population and the gas yield.

It is concluded from the study that if the surface area for the attachment of microbes is increased,

1. The gas yield for a reactor and methane content in it increases for the same HRT.
2. The hydraulic retention time (HRT) of an anaerobic reactor decreases for the same gas yield.
3. Daily gas yield per unit feed rate increases. It also increases by reducing HRT.

# CHAPTER ONE

# INTRODUCTION

## 1.1 MOTIVATION:--

The people of our country, as those most of the other developing nations, are suffering from an energy crisis. Until recently, the prime source of energy has been fossil fuels which are depleting very fast. The use of fossil fuels has caused tremendous environmental pollution and dwindling reserves of fossil fuels. In the light of the increasing demand of energy, population explosion and increasing environmental pollution, there is an urgent need to explore renewable and pollution free alternate sources of energy.

Particularly in developing nations where the cattle and human population is pretty large, the biogas has emerged to be a very attractive alternative source of energy.

There are instances where we require very low amount of energy which can very easily be produced from certain waste materials. Also we have to look into the energy needs of our rural areas where rural electrification is either not there or may not be forthcoming in the foreseeable future due to high cost of transmission lines etc. The subsidized prices of kerosene, diesel etc. have not helped much since most people cannot afford to buy

them anyway. This results in over use of firewood from trees, which causes deforestation and land slides. People also have to resort to use dung-cakes as fuel, but this practice deprives their land of much needed natural manure reducing the crop yield. Also the smoke resulting from the burning of dung cakes and other agricultural residues causes eye diseases particularly among the village women.

In order to partly take care of the problems mentioned above, attempts are in progress to properly manage the organic wastes e.g. agricultural, industrial, kitchen waste and animal as well as human excreta. Using these wastes, the biogas can be produced by anaerobic decomposition. This decomposition is brought about by the anaerobic bacteria (anaerobes). The wastes are usually used as a feed stock for biogas plants. In addition to producing good fuel gas (containing 60 % methane, 40 % carbon dioxide and small amounts of other gases such as hydrogen sulfide etc.), the anaerobes in biogas plant also decompose the wastes to form good manure for the farms which is pretty rich in nitrogen, phosphorus and humus. The biogas produced can be used as an excellent source of energy for kitchen stoves, biolamps, gas engines, for irrigation etc.

If one goes by the conventional route then 100 kg of green cattle dung has 16 kg of dry dung which is equivalent to 250 MJ of gross energy. But 10 % stove (chulah) efficiency reduces it to only 25 MJ of net energy but for the improved stove having 22 %

efficiency, the value will becomes 55 MJ. But by the biogas route, it shows that 100 kg of fresh cattle dung produces 4.0 $m^3$ of biogas having 21.4 $MJ/m^3$ as heating value giving 85.6 MJ of gross energy. A 40 % efficient burner using the biogas results in approximately 38 % more energy in comparison to that from the least efficient chulah (stove). If an improved burner of 55 % efficiency is used, the net gain in energy is ≅ 89 % ( Kishore et al., TERI).

Government of India through Department of Non conventional Energy Sources (DNES), and with the assistance of various state government and Khadi Village and Industries Commission (KVIC) is propagating various programs to adopt this technology. For example in financial assistance scheme the grant of loans are available ranging from 25 % to 100 % of the total construction cost. Technical guidance is also provided in different manner. Self employment schemes are also in progress (Anon., 1984).

Biogas plant itself comprises a digester of adequate size to ferment the feed in an efficient manner. The gas holder covers this digester to collect and divert the gas produced through a pipe to the place of its use. As far as the principle of operation of the plant is concerned, the influent in the form of slurry of waste materials and water goes into the digester and it displaces the same amount of already accumulated digested slurry as the effluent from outlet and maintains the same amount of the biomass inside the digester for decomposition into the biogas.

There are several types of problems in acceptance of this technology e.g. motivational , sociological, financial, operational, organizational and technical. One of the technical problems in biogas plant is the longer duration needed to completely decompose the waste materials. This duration is in some way some way a measure of the digester volume per unit daily feed rate, also known as the " Hydraulic Retention Time" (HRT). A large HRT results in a large volume of a digester and therefore a high cost.

The main motivation behind the present study is to reduce the HRT for a given gas yield or in other words increase the gas yield for a given HRT.

## 1.2 SCOPE OF THE PRESENT STUDY:--

As mentioned earlier, one of the technical problems in biogas plant is longer HRT. Even for a small capacity of biogas plant the digester volume becomes fairly large. A small capacity plant also therefore becomes much too expensive for common villagers. In view of this, it is essential to reduce the HRT and therefore the cost of the plant.

In order to reduce HRT, the concept of increasing the microbes population by increasing surface area for their attachment has been used in so called advanced reactors where some inert media providing a large surface area is immersed in the slurry to be decomposed. These reactors find applications in waste water treatment. Using this concept, the objective set for

the study were as follows:

(1) Measurement of gas yield from five reactors with three of them having different inert media under controlled conditions.

(2) Measurement of Volatile Solids (VS) of influent and effluent slurry to determine the VS consumed as a measure of gas produced.

(3) Measurement of the Chemical Oxygen Demand (COD) to determine COD consumed for the gas production.

In the present study, the experimentation is limited to small reactors of 2 litre capacity. Additional experiments will have to conducted on bigger reactors under controlled environmental conditions and under ambient conditions to make the study useful for the commercial exploitation in the design of biogas plant.

## 1.3. ORGANIZATION OF THE THESIS:--

This chapter gives a brief introduction of the subject and outlines the scope of the present study. Chapter two gives a review of the various biogas plant designs followed by a discussion on advanced reactors to reduce the hydraulic retention time. Chapter three describes in detail the experimental set-up and procedure. Chapter four gives the data collected on all five reactors used in the present study and discusses the results obtained.

# CHAPTER TWO

# LITERATURE SURVEY

## 2.1 ANAEROBIC DIGESTION PROCESS

Anaerobic digestion refers to the treatment of waste material in the absence of oxygen by action of bacteria. Bacteria are the fundamental organisms in the stabilization of organic wastes and therefore of basic importance in the biological treatment. Individual bacteria cells range in size from approximately 0.5 to 5.0 microns in rod, sphere and spiral shapes, and occur in a variety of forms: individuals, pairs, packets, and chains. Bacteria reproduces by binary fission and take 20 to 30 minutes under ideal environmental condtions to grow, mature and fission. Anaerobes are the heterotrophic bacteria, which oxidize organic matter in complete absence of the dissolved oxygen, but can also respire and multiply in its absence.

The process of anaerobic digestion is carried out by a wide variety of bacteria that can be categorized into two main groups- (i) acid forming bacteria and (ii) methane forming bacteria. The acid formers are facultative or anaerobic bacteria which metabolize organic matter (i.e.carbohydrates, protiens, fats etc.) forming organic acids (volatile acids) as an end products, along with carbon dioxide and methane associated with oxidation of fats to organic acids. Acid splitting methane formers use organic acids as substrate ( with the help of intra cellular enzymes ) and produce gaseous end products of carbon dioxide and methane. These

methane formers are strict anaerobes which are deactivated by the presence of dissolved oxygen and inhibited by the presence of oxidized compounds (Clark et al., 1971).

Process in first phase is represented by the reaction equation:

$$\text{Organic Matter} \Longrightarrow \text{Intermediate} + CO_2 + H_2O + \text{Energy}$$

Process in second phase is represented by the reaction equation:

$$\text{Organic Acids (Intermediates)} \Longrightarrow CH_4 + CO_2 + \text{Energy}$$

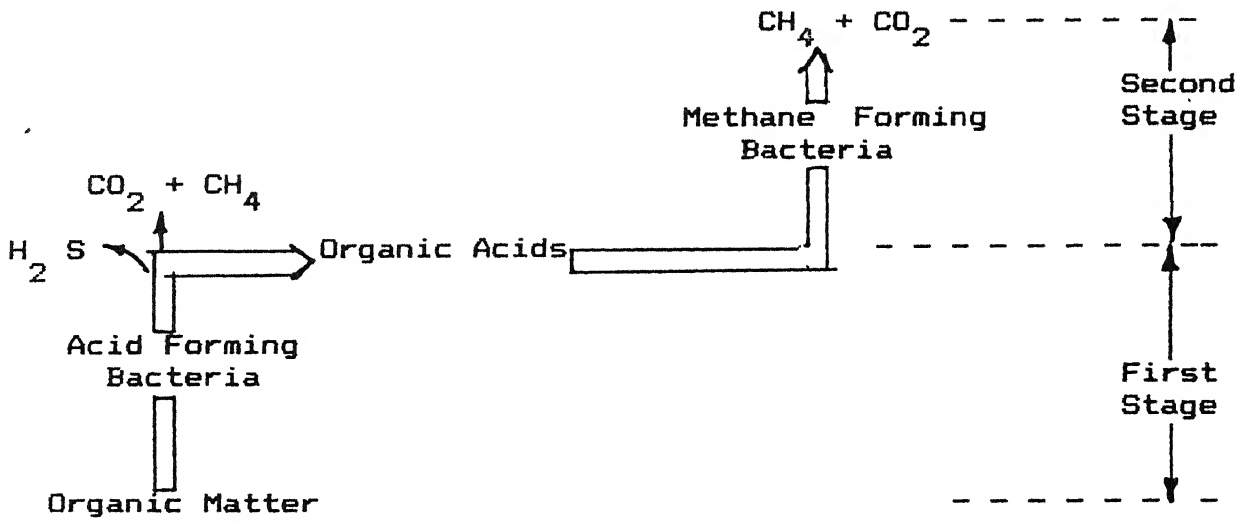


Fig. 2.1 Population Dynamics in Anaerobic Digestion

Figure 2.1 portrays the relationship between the two bacterial stages in digestion of organic matter. Both major groups of bacteria must cooperate to perform the overall gasification of the organic matter (Clark et al., 1971).

The first stage provides the food (organic acids ) for the second stage where these organic acids are consumed, preventing

excessive acid accumulation. In addition to producing food for the methane forming bacteria, acid formers also reduce the environment to one of strict anaerobic by using the oxidized compound and excreting reducing agents. The imbalance in the population dynamics causes the problems in operating anaerobic systems (Clark, et al 1971).

## 2.2 FACTORS AFFECTING THE GAS YIELD

There are a large number of factors which significantly affect the gas yield. These are describe below:

### 2.2.1. Temperature

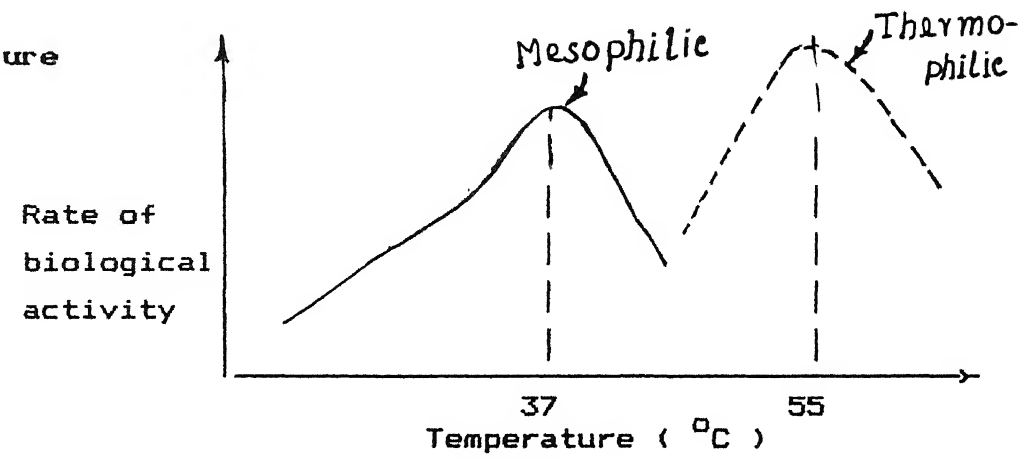


Fig 2.2 Effect of Temperature on Rate of Biological Activity

Bacteria are classified as psychrophilic (cold loving), thermophilic (heat loving) and mesophilic (moderation loving). Psychrophilic bacteria grow best at temperature slightly above freezing ($4^oC$ to $10^oC$), but are least significant. Thermophilic bacteria like optimum temperature range (50 to $55^oC$). Mesopholic bacteria grow best in the temperature range of $20^oC$ to $40^oC$, but anaerobic digestion occurs optimally at about $35^oC$ (Pandey and Kate, 1983; Clark et al., 1971).

### 2.2.2 Loading Rate

Loading rate means the amount of fermentable organic matter or volatile materials that are to be fed into the digester per cubic meter of digester capacity. This is adjusted for various feeding materials e.g. waste water, cow dung, kitchen waste etc. Loading rate in digesters in terms of volatile solids (VS) added can vary from 0.7 to 5 kg of VS/cu m/ day (Stafford and Houghes, 1980). One of the major problem in the anaerobic digestion of animal wastes is the ' built up' of toxic concentration of ammonia produced from the high nitrogen content of the digested slurry (manure). There may be as much as 0.4 gm nitrogen/kg waste from the cattle, 0.9 from pigs and 0.15 from human beings (Jagadeesh and Devi, 1983).

### 2.2.3 Solid Cocentration

It is the amount of fermentable solid of charge into the unit volume of slurry. Ordinarily 7-9% solid concentration is best suited, e.g 4 parts of the cow dung mixed with 5 parts of water brings about 8% or little higher solid concentration. The methane forming bacteria can be adversely affected by excess concentration of oxidized compounds, volatile acids, soluble salts, and metal cations (Jagadeesh and Devi, 1983).

### 2.2.4 Nutrient Concentration

Bacterial nutrients consist of nitrogen, phosphorous and potassium (NPK), minor elements and some harmones. Sufficient amount of nutrients are needed for fast fermentation process. The bacteria require mainly carbon and nitrogen in order to live, but

they use up carbon almost 30 to 35 times faster than the nitrogen, hence optimum C/N ratio is maintained at about 30:1. *The basic idea of anaerobic fermentation in biogas plant is to convert all the available carbon into methane and carbon dioxide with as little loss of available nitrogen as possible.* This ratio is maintained by adding some extra additives e.g. mollasses, oil cakes, animal urine, chemical fertilizer, etc.

Accidental presence of oxygen into the reactor will cause aerobic fermentation which doesn't produce methane, hence reduces the gas yield.

Presence of some toxic substances like copper some times, if found in excessive quantity inhibits the gas production, but such type of occurrence is very rare.

**2.2.5 pH Value**

The hydrogen ion concentration of the culture medium has a direct influence on microbial growth. Most biological treatment systems operate best in a neutral environment. General range for operation of activated sludge system is in between pH 6.5 to 8.5. At pH of 9.0 and above, microbial activity is inhibited. Below pH 6.5 fungi are favored over bacteria in the competition for food. The methane forming bacteria in anaerobic digestion have a much smaller pH tolerance range. General limit for anaerobic digestion is 6.7 to 7.4 with optimum operating range of pH being 7.0 to 7.1. If the pH value becomes too high, the acid formed in the digestion process will bring it down, but if it becomes too low (due to over feeding), the gas producing bacteria will be unable to use up the acid quickly enough and the digestion will be stopped. To

maintain a near optimum value, some alkaline matter like ash or lime may have to be added to the slurry in the digester (Clark et al., 1971).

### 2.2.6 Retention Time

The retention time is the time for which the fermentable material resides inside the digester for complete fermentation. There are three types of retention times defined as described below (Jagadeesh and Devi, 1983).

(a) **Hydraulic Retention Time (HRT):** It is the ratio of the active slurry volume in the reactor to the volumetric feed rate. It is generally chosen for the design purpose and should be as small as possible (Raman et al., TERI).

(b) **Solid Retention Time (SRT):** It is the time for which the solids (i.e. microbes attached to each other and forming semi solid sludge) are retained in the reactor for the complete anaerobic treatment.

McCarty's studies of kinetics of anaerobic digestion processes indicated the importance of the biological solid retention time (SRT), and gave the relation (Douglas, 1976).

$$\mathrm{SRT} = \frac{M}{dM/dt} = \frac{\text{Suspended solids in the system}}{\text{Rate of suspended solids removed from the system}}$$

(c) **Effective Retention Time (ERT):** It is the time for which the slurry stays in the reactor to be digested completely. If the feeding is of continuous type, then both HRT and ERT are more or less equal.

### 2.2.7 Types of flow

The period for which the slurry stays throughout the space of the reactor is not same. In some locations, the digested slurry stays in the reactor for a longer duration, whereas in others locations the undigested slurry comes out pretty soon. This time of slurry stay within the reactor is known as residence time distribution. This residence time can be maintained uniform to some extent by suitable adjustment of the flow of the slurry by adjusting the position of inlet and outlet (Raman et al., TERI).

### 2.2.8 Pressure

The rate of evolution of gas bubbles formed inside the slurry depends upon the pressure above the slurry level. The increased pressure above the slurry may keep the gas bubbles trapped inside the slurry itself and hence may reduce the gas evolution rate.

### 2.2.9 Media and Surface Area for the Attachment of Microbes

The microbes that are moving about in the reactor may come out with digested slurry, but these should stay in the reactor for a longer duration as they convert the organic matter into biogas. It is possible to retain them inside the reactor if these can be attached to a surface of an inert media which can increase the gas yield (Iza et al., 1991).

## 2.3 BIOGAS PLANT DESIGNS

There are many institutions working in the area of biogas technology which have come up with various biogas plant designs. These are briefly described in this section. Conceptually only

two types of biogas plants have been developed namely the " *Floating Drum Type* " and the " *Fixed Dome Type* ". the former was first introduced by Khadi Village & Industries Commission (KVIC) in which gas holder remains floating in the slurry. It provides the gas at constant pressure. In the latter i.e. the fixed dome type, the digester and gas holder are built as one unit. The entire plant is made of brick masonry and is plastered from both inside as well as outside. The plant designs developed so far by the different organizations, fall into one of the above categories.

### 2.3.1 Floating Drum Designs of Biogas Plants

1. KVIC MODEL

KVIC has developed plants of the capacity 2 $m^3$ and above mainly of the vertical type, but where ground water level is high, a horizontal type of plant is also recommended. The digester is in the form of a circular well built mostly below ground level using brick masonry 230 mm. thick and plastered. The gas holder is a steel drum floating in the slurry. A central guide system consisting of two pipes one sliding over the other is provided. The gas holder is stiffened with radial and vertical mild steel angles which also constitute the scum breaking arrangement (see figs.2.3 & 2.4). Initially the gas holder is painted by a corrosion resistant paint and then repainted once a year. This design is basically used for cattle dung as a biomass in 4:5 ratio of cattle dung to water. The data for some of plant designs based upon this model are given in Tab. 2.1 (Shelat, 1983, Jagadeesh and Devi, 1983).

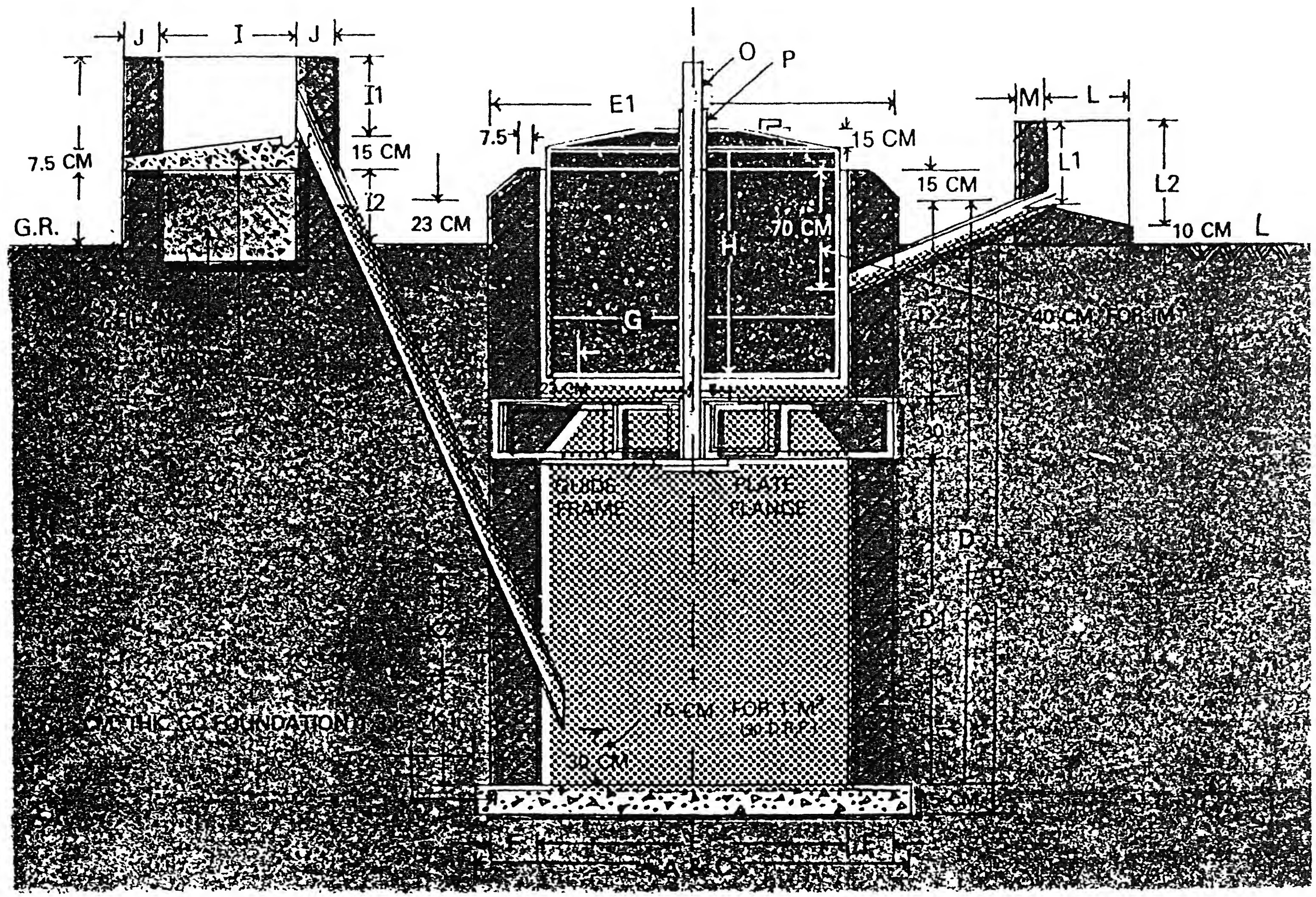


Fig.2.3 KVIC Model of Biogas Plant ( 1 to 3 $m^3$)

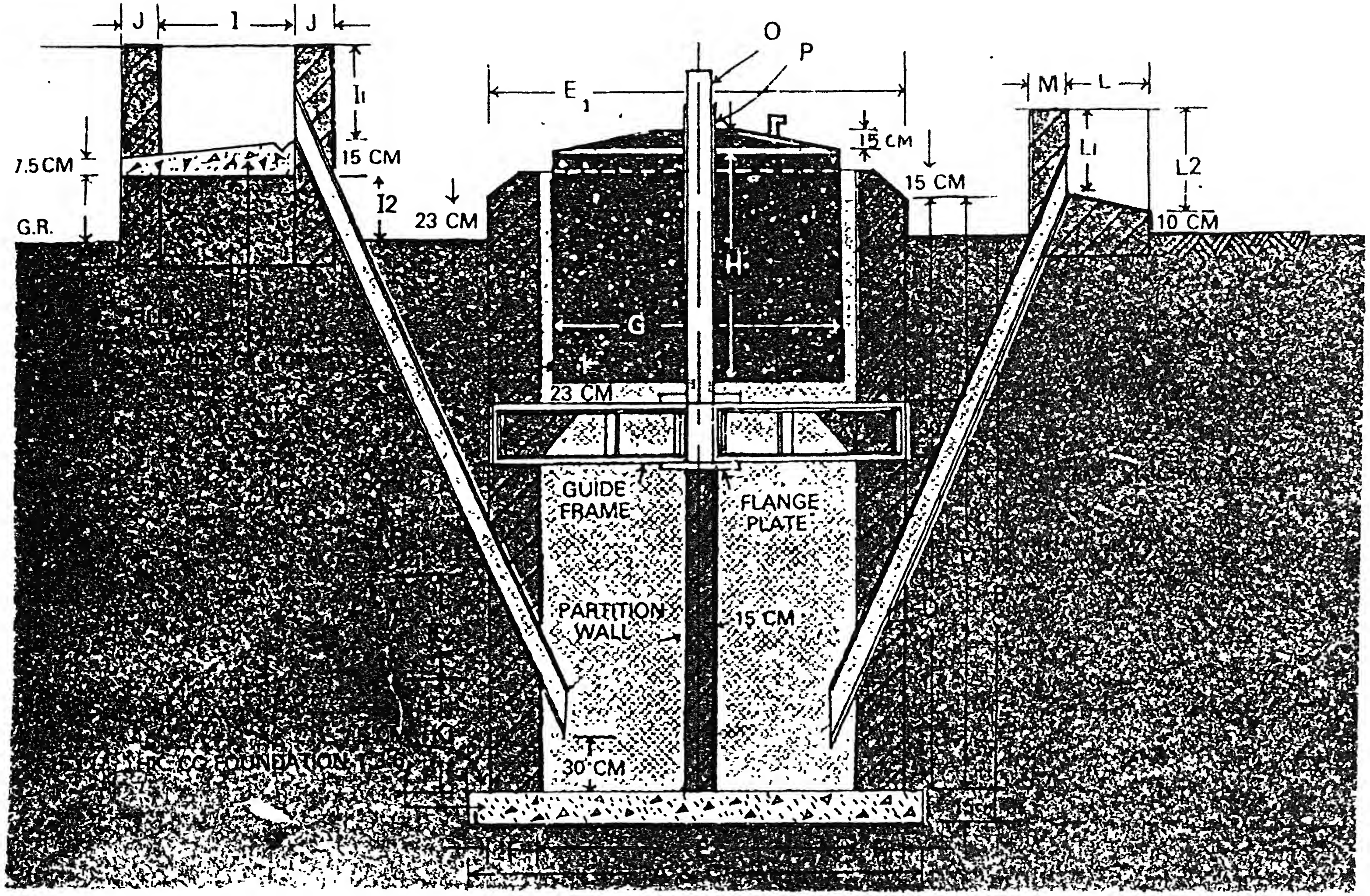


Fig.2.4 KVIC Model of Biogas Plant ( 4 to 10 $m^3$)

TABLE 2.1

KVIC TYPE BIOGAS PLANTS

| PARTICULARS | SYMBOL | D.R.P. | $2M^3$ | $3M^3$ | $6M^3$ | $10M^3$ |
|---|---|---|---|---|---|---|
| Excavation dia | A | 30/40 | 1.96 | 2.21 | 2.81 | 3.36 |
| Excavation depth (ht) | B | 30 | 2.02 | 2.17 | 2.27 | 2.47 |
| Excavation depth | B | 40 | 2.72 | 2.92 | 3.07 | 3.32 |
| Foundation dia | C | 30/40 | 1.96 | 2.21 | 2.81 | 3.36 |
| Height of gas plant digester | D | 30 | 2.21 | 2.25 | 2.35 | 2.55 |
| Height of gas plant digester | D | 40 | 2.80 | 3.00 | 3.15 | 3.40 |
| Height of digester bottom | $D_1$ | 30 | 0.80 | 0.95 | 1.05 | 1.00 |
| Height of digester bottom | $D_1$ | 40 | 1.50 | 1.70 | 1.85 | 1.85 |
| Height of digester top | $D_2$ | 30 | 1.00 | 1.00 | 1.00 | 1.25 |
| Height of digester top | $D_2$ | 40 | 1.00 | 1.00 | 1.00 | 1.25 |
| Digester dia (inner) | E | 30/40 | 1.35 | 1.60 | 2.20 | 2.75 |
| Digester dia (outer) | $E_1$ | 30 | 1.81 | 2.06 | 2.66 | 3.21 |
| Digester dia (outer) | $E_1$ | 40 | 1.81 | 2.06 | 2.66 | 3.21 |
| Wall thickness | F | 30/40 | 0.23 | 0.23 | 0.23 | 0.23 |
| Gas holder dia | G | 30/40 | 1.25 | 1.50 | 2.00 | 2.60 |
| Gas holder height | H | 30/40 | 1.00 | 1.00 | 1.00 | 1.25 |
| Inlet tank LxW | I | 30/40 | .38x.38 | .75x.75 | .90x.90 | .70x.70 |
| Inlet height | I1 | 30/40 | .38 | .45 | .45 | .60 |
| Inlet tank height | I2 | 30/40 | 3.55 | .38 | 5.25 | .60 |
| Wall thickness | J | 30/40 | .15 | .15 | .45 | .40 |
| Length of AC pipe ( 10 dia) | K | 30 | 2.60 | 2.60 | 2.70 | 2.90 |
| Length of AC pipe ( 10 dia) | $K_1$ | 40 | 3.00 | 3.50 | 3.50 | 3.70 |
| Length of AC pipe ( 10 dia) | $K_1$ | 30 | .60 | .65 | .60 | .60 |
| Length of AC pipe ( 10 dia) | $K_2$ | 40 | .70 | .60 | .60 | .60 |
| Outlet tank LxW | L | 30/40 | .45x.45 | .45x.45 | .45x.45 | .45x.45 |
| Outlet tank height | L1 | 30/40 | .45 | .45 | .45 | .45 |
| Outlet tank height | L2 | 30/40 | .50 | .50 | .50 | .50 |
| Wall thickness | M | 30/40 | .15 | .15 | .15 | .15 |
| Length of AC pipe (10 dia) | N | 30 | .80 | 1.10 | 2.30 | 2.50 |
| Length of AC pipe (10 dia) | N | 40 | .90 | 1.10 | 3.00 | 3.40 |
| G I pipe (M S pipe) for CGF (4 dia) | O | 30/40 | 1.95 | 2.00 | 2.05 | 2.40 |
| M S pipe for gas holder | P | 30/40 | 1.15 | 1.15 | 1.25 | 1.50 |

## 2. PRAGATI MODEL

Pragati model is also a floating drum type. It has a hemispherical digester and the bottom of the digester is slightly curved (see Fig.2.5). This hemispherical digester is advantageous in the sense that it provides a larger volume with the same material of construction, but increases the degree of difficulty in construction. Inlet and outlets are made with pipe (Anon., KVIC). The data for the some of the plant designs based upon this model are given in Table 2.2.

## 3. TAIWANESE MODEL

In This design, digesters are similar in principle to the KVIC model, but the recommended types have either one or two rectangular chambers, the latter chamber being interconnected, with a floating gas dome on the first chamber as shown in Fig. 2.6 The main source of animal excreta in these plants is pigs and for a digester used on a 20 pig farm, the size of first chamber is 1.12 m x 1.12 m x 1.83 m deep and of second 2.54 m x 1.47 m x 1.83 m deep. Third chamber is only for storage of digested sludge and can be of any convenient size (see Fig. 2.6). The digesters are manually operated, stirring being done by a rope pulled paddle. Emphasis is laid on use of the digested sludge in small, shallow pond for the growth of algae. Although the digesters are simple in costruction, but on the whole they are designed for use by much richer farmers than those of India (Hobson et al., 1981).

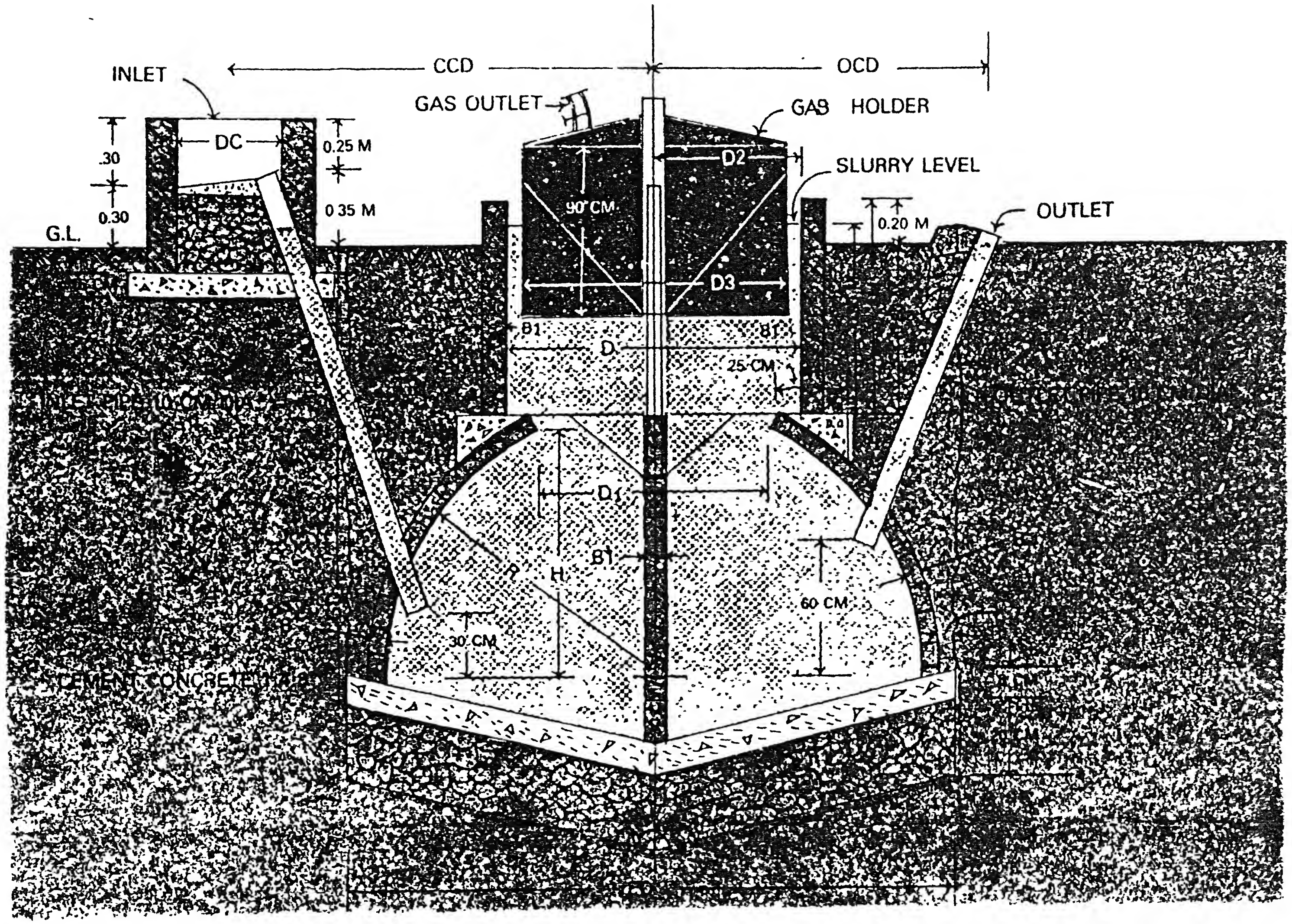


Fig.2.5 Pragati Model of a Biogas Plant

TABLE 2.2

Details Dimensions of Pragati Model of a Biogas Plants

| Particulars | Symbols | 2 $M^3$ | 4 $M^3$ |
|---|---|---|---|
| Excavation diameter | ED | 2.80 | 3.30 |
| Excavation depth excluding conical portion | GD | 2.21 | 2.25 |
| Hemispherical portion radius | R | 1.25 | 1.50 |
| Thickness of shell | B | 7.00 | 11.00 |
| Top opening of shell diameter | D1 | 1.20 | 1,65 |
| Vertical height of top level of shell o opening top of shell | H | 1.20 | 1.25 |
| Upper cylindrical portion dia | D | 1.40 | 1.90 |
| Upper cylindrical portion width | B1 | 11.25 | 11.25 |
| Diameter | DC | 0.60 | 0.80 |
| Distance between digester and inlet chamber | CCD | 1.90 | 2.25 |
| Distance between digester and outlet pipe | OCCD | 1.50 | 1.75 |
| Length of inlet pipe (10 cm dia) | IPL | 2.15 | 2.25 |
| Length of outlet pipe (10 cm dia) | OPL | 1.35 | 1.60 |
| Diameter of gas holder | D | 1.30 | 1.75 |
| Top and bottom rings 12 mm dia of M S bar | RN | 4.10 | 5.55 |
| Vertical Support; 6 Nos (12 mm dia) Of M S bar | VS | 6*0.9 | 6*0.9 |
| Top and bottom suppor spokes (4+6 12 mm dia bar | SP | 4*0.62<br>6*0.62 | 4*0.88<br>6*0.85 |
| Scum breaker flats (40 mm 5 mm);4 N | S | 4.0 | 4.25 |
| M.S.sheets(2.5 m o.9 m) 2.0 mm | | 2.25 | ----- |
| M.S.sheets(2.5 m o.9 m) 2.5 mm | | ----- | 3.25 |
| M.S. pipe of 62.5 mm of internal dia | | 1.20 | 1.20 |
| Outlet shocket 25 mm internal dia | Nos. | 2 | 2 |

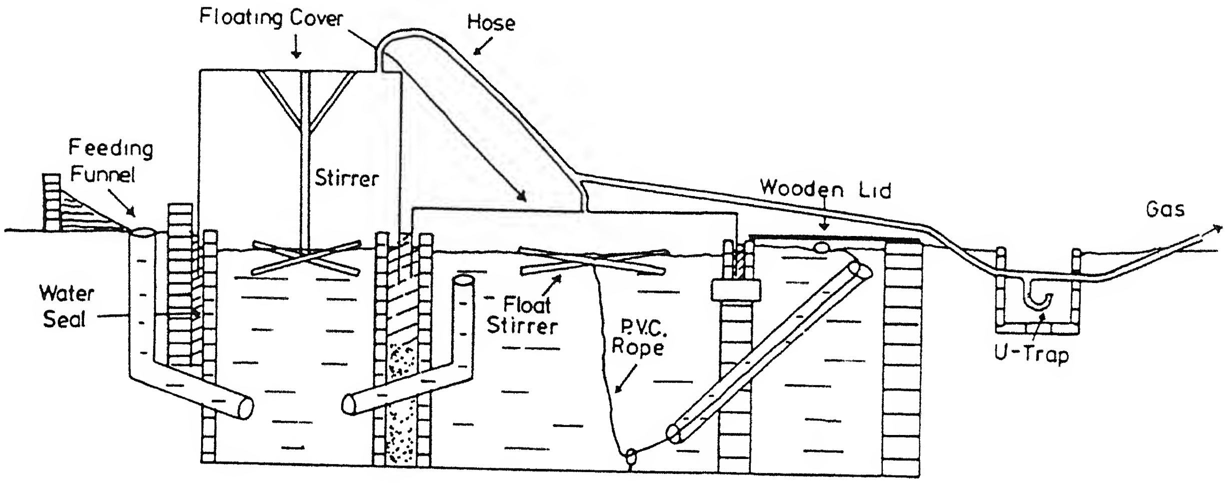


Fig.2.6 Typical Taiwanese Design of a Biogas Plant

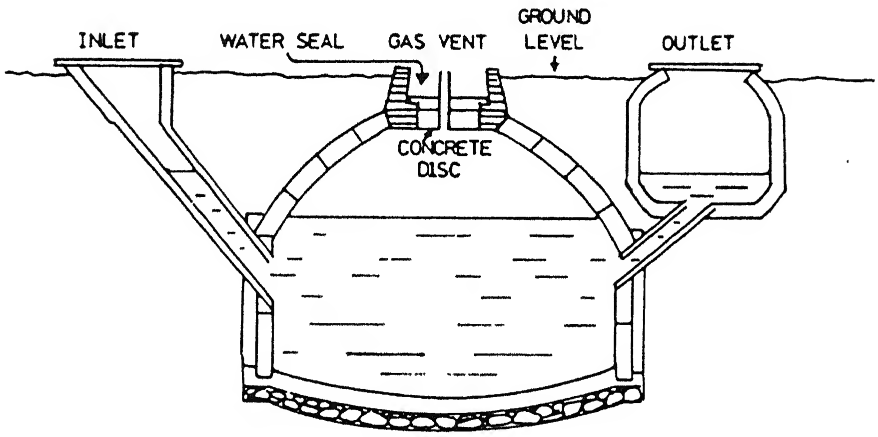


Fig.2.7 A Typical Chinese Type of Biogas Plant

4. INDIAN AGRICULTURE RESEARCH INSTITUTE (IARI) MODEL

The IARI designs are basically similar to those of KVIC. Here it is attempted to saving the cost by avoiding plastering of the digester wall. This leads to percolation of the slurry into the surrounding soil and weakening the structure. The vertical movement of the gas holder is controlled by a system of pulleys and counter weights which add to the cost. There is no provision for the scum breaking. But no information about the number of these plants is available.

2.3.2 Fixed Dome Designs of Biogas Plants:--

1. CHINESE MODEL:--

The digester shape of this model is somewhat similar to the Indian Deenbandhu model. The digester of a chinese model comprises of two spherical segments at the top and bottom which are connected through a cylindrical portion The digester is made water- and gas- tight by application of layers of cement or motars of various types. It also provides a concrete cover of disc shape on the top of the digester to facilitate the easy cleaning when required (see Fig.2.7). Loading and unloading is done manually. Although, the construction of these plants is simple, yet it is expensive for a comman farmer. This plant is used for animal and vegetable wastes (Hobson et al., 1981; Shelat, 1983).

2. JANATA MODEL

This plant was developed by the Planning Research and Action Division (PRAD) of U.P. The retention time is about 50 to 60 days and organic loading rate is about 3.5 kg/cu.m. of gas produced.

Gas loading capacity is about 60% of the gas yield capacity of the plants. The roof is in the form of brick dome plastered with cement and painted on the inside and having an earth fill at the top. The inlet and outlets are made large enough in the form of tanks, for the people to enter into the digester for cleaning purpose as shown in Fig.2.8 ( Jagadeesh and Devi, 1983). The dimensional details for some of the designs based upon this model are given in Table 2.3 and also shown in Fig.2.8.

Modified versions of these plants are designed to reduce the cost of the plant as well as to increase the gas yield by providing a scum breaking device. A water heater cocept was suggeated in the design for higher gas yield during the winter seasin using solar energy ( Gupta et al., 1988).

3. DEENBANDHU MODEL

This design has a curved bottom and a hemispherical top joined at their bases in one unit and made of brick masonry. Inlet is in the form of a pipe which directly connects the digester to the slurry mixing tank and outlet tank is also directly connected to the digester (see Fig.2.9 ). In this plant, the slurry displaced out of the gas storage chamber is stored in the outlet displacement chamber. It does not go to the inlet side because of difference in slurry head on two sides. The data for some of the plant designs based upon this model are given in Table 2.4 (Myles, 1987).

4. MURUGAPPA CHETTIAR RESEARCH CENTRE (MCRC) MODEL:--

Murugappa Chettiar Research Centre(MCRC), Madras has

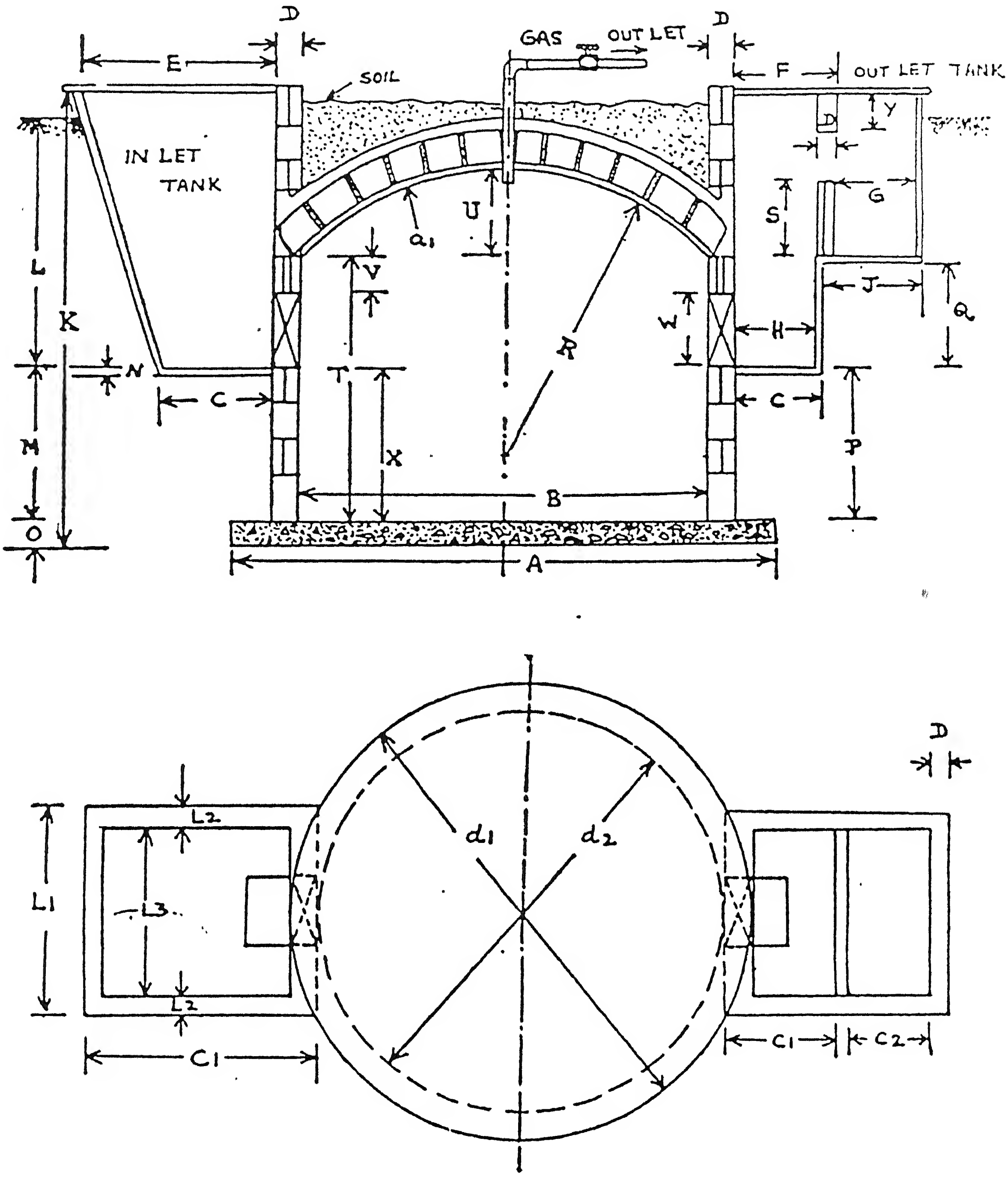


Fig.2.8 Janata Biogas Plant

TABLE 2.3

Dimensional Details of Janata Biogas Plants

| G ($m^3$/day) | A (m) | B (m) | C (m) | D (m) | E (m) | F (m) | G (m) | H (m) | J (m) |
|---|---|---|---|---|---|---|---|---|---|
| 2.0 | 2.750 | 2.370 | 0.810 | 0.115 | 0.850 | 0.850 | 0.610 | 0.610 | 1.040 |
| 3.0 | 3.100 | 2.720 | 0.810 | 0.115 | 1.215 | 1.215 | 0.610 | 0.610 | 1.405 |

| G ($m^3$/day) | K (m) | L (m) | M (m) | N (m) | O (m) | P (m) | Q (m) | S (m) | T (m) |
|---|---|---|---|---|---|---|---|---|---|
| 2.0 | 2.280 | 1.425 | 0.530 | .075 | 0.100 | 0.530 | 0.690 | 0.660 | 1.345 |
| 3.0 | 2.625 | 1.560 | 0.690 | 0.075 | 0.150 | 0.690 | 0.755 | 0.730 | 1.575 |

| G ($m^3$/day) | U (m) | W (m) | X (m) | Y (m) | R (m) | $A_1$ (m) | $L_1$ (m) | $L_2$ (m) | $L_3$ (m) |
|---|---|---|---|---|---|---|---|---|---|
| 2.0 | 0.520 | .61 .61 | ---- | .115 | 1.610 | .140 | 0.840 | 0.115 | 0.610 |
| 3.0 | 0.596 | .61 .61 | .750 | 0.230 | 01.860 | 0.140 | 1.030 | 0.115 | 0.800 |

| G ($m^3$/day) | $d_1$ (m) | $d_2$ (m) | $c_1$ (m) | $c_2$ (m) |
|---|---|---|---|---|
| 2.0 | 2.600 | 2.370 | 0.850 | 0.610 |
| 3.0 | 2.950 | 2.720 | 1.215 | 0.610 |

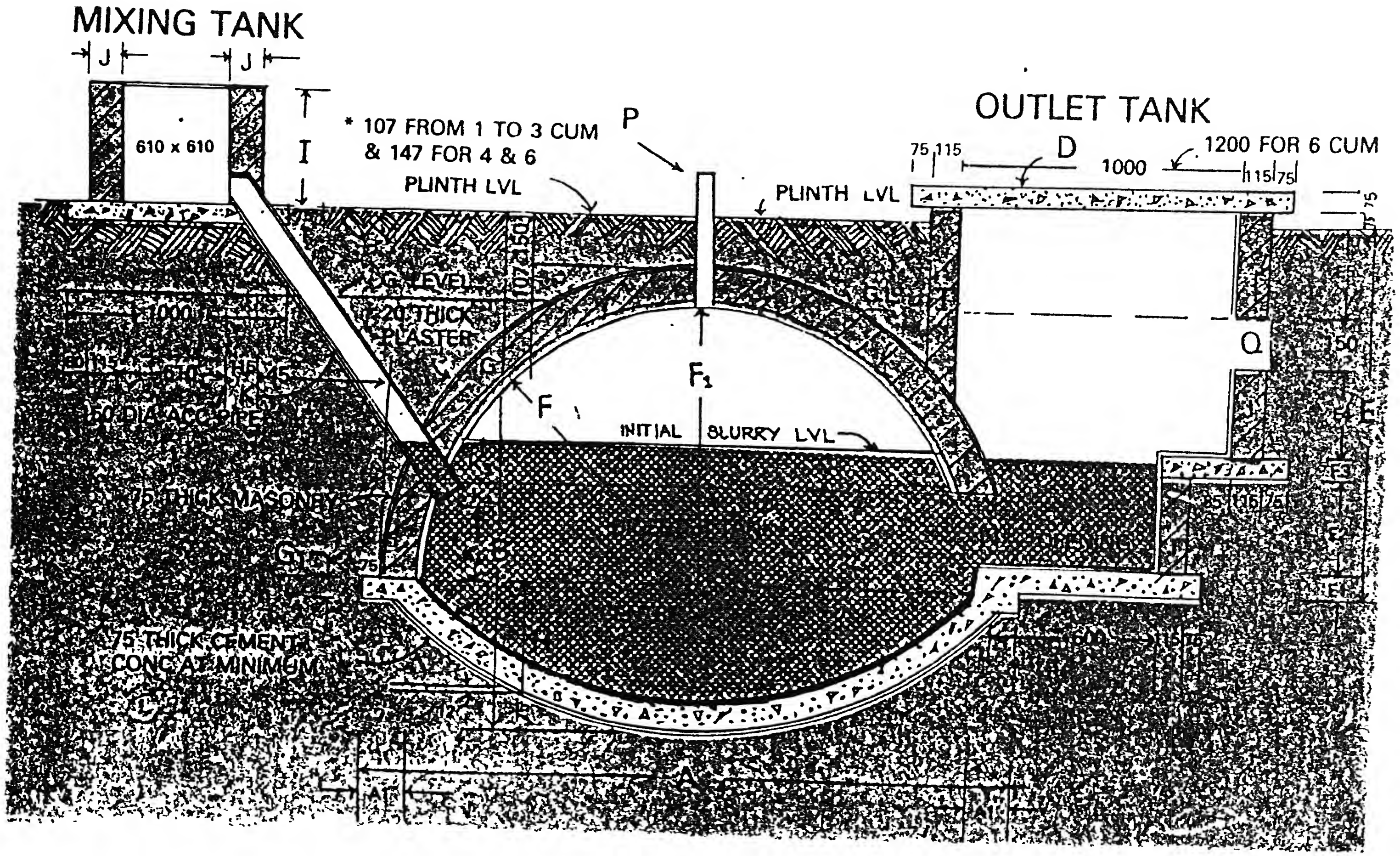


Fig.2.9 Deenbandhu Biogas Plant

TABLE 2.4
Dimensional Details of Deenbandhu Biogas Plants

| Particulars | Symbols | $2\ M^3$ | $4M^3$ |
|---|---|---|---|
| Circular portion of the main tank | A | 2.85 | 3.48 |
| Wall thickness of the main tank | A1 | .150 | .15 |
| Depth of the main tank | B | 1.875 | 2.338 |
| Outlet chamber (Rectangular) | D | 1.380x2.040 | 1.380x3.110 |
| Depth of outlet chamber | E | 1.532 | 1.887 |
| Bottom portion of the outlet tank | E1 | 0.075 | 0.075 |
| Bottom portion of the outlet tank | E2 | .570 | .810 |
| Bottom portion of the outlet tank | E3 | .075 | .075 |
| Bottom portion of the outlet tank | E4 | .400 | .460 |
| Bottom portion of the outlet tank | E5 | .262 | .317 |
| Radius of the upper hemispherical portion dome | F | 1.275 | 1.590 |
| Height of the dome at the centre | F | 1.275 | 1.590 |
| Wall thickness of the dome | G | .075 | .115 |
| Projection in cement concrete | G1 | .075 | .150 |
| Height of the digester from C.C base | H | .510 | .636 |
| Height of inlet tank (from P.L.) | I | .610 | .610 |
| Thickness of the wall | J | .115 | .115 |
| Length of inlet pipe (150 mm dia) | K | 1.8 | 1.8 |
| Height of pipe from centre line | K1 | .30 | .30 |
| Height of pipe from bottom to top | K2 | .245 | .420 |
| Height of pipe from top to slurry level | K3 | .175 | .240 |
| Outlet slurry opening hole | N | .60x.295 | .60 x.645 |
| Outlet slurry discharge | O | .15 x.15 | .15x.15 |
| Gas outlet pipe (GI) 12.7 mm dia | P | .175 | .175 |
| Bricks required Nos | | 1000 | 1690 |
| Cement | | 14 bags | 22 bags |
| Stone chips | | 40 cft | 60 cft |
| Sand | | 40 cft | 60 cft |
| Course sand | | 40 cft | 60 cft |
| A.C. pipe 150 mm internal dia | | 6 ft | 6 ft |
| G.I. pipe 12.7 mm dia with socket | | 7" | 7" |
| Iron bars ( 6 mm dia) for outlet tank cover | | 7 kg | 12 kg |

developed a new design of a bogas plant which consists a digester in the form of a cylindrical underground well with brick walls and concrete floor. The gas holder consists of a half geodesic dome made of PVC pipes and steel rings for joints. A vinyl bottom made of high density polyethylene (HDPE) sheet is screwed inside the dome. To start with, the HDPE sheet is in a collapsed condition. As the gas is produced , the balloons get filled and press against the geodesic dome. A water trough is provided around the digester. It prevents the leakage of gas through the water seal, if filled say up to 200-300 mm.of water. Hooks around the gas dome help to anchor the structure so that it does not fly off under pressure.The function is some what similar to a variable pressure type plant. Its main aim is to reduce the cost of the plant and also utilize village artisans for making the plants (Jagadeesh and devi, 1983).

5. TAMIL NADU AGRICULTURE UNIVERSITY (TNAU) MODEL:--

The work at Tamil Nadu Agricultural Univesity (TNAU) in Coimbatore has been done entirely on the closed type of plants. They have developed four designs. In all of their plants, a retention period of 15 days is used. They add methane producing bacteria at one third the height of slurry at a temperature of $30^{o}$to $40^{o}C$ to compensate for the low retention time . They concluded from their studies on these plants that two third volume of the slurry and one third volume of the gas was the optimum for the maximum gas production. On this basis they have developed the following designs ( Jagadeesh and devi, 1983).

**(a) Mobile Plant (Cylindrical):** is made of 10 gauge mild steel horizontal cylinder 1.14 m dia x1.8 m length for 2 $m^3$ of gas per day capacity with suitable arrangement for inlets and outlets.

**(b) Mobile Plant (cube):** was an experimental model of cube size 1.83 m x 1.83 m x 1.83 m for 2 $m^3$ capacity from 10 gauge mild steel. The total volume was 6.13 $m^3$ out of which 2 $m^3$ w. used for the gas storage.

**(c) Modified janata Plant:** was similar to the PRAD model described above with some modifications.

**(d) Cheap Underground Biogas Plant:** is a closed type of plant similar to the Janata Biogas Plant. The unit consists of a cylindrical structure consisting of one bowl at the top and other at the bottom. The bottom foundation is spheroid 75 mm thick cast in cement concrete. The cylindrical masonry structure is made 114 mm thick. The top portion of the gas holder is made of dome structure containing wire mesh embedded in cement concrete. The slurry capacity of the digester is 5.7 $m^3$ and the gas holding capacity is 1.9 $m^3$. The plant produces approximately 2.5 $m^3$ of gas per day (Jagadeesh and Devi, 1983).

## 6. NOVEL BIOGAS PLANT MODEL BY WARDHA

The ' Centre of Science for Village' (CSV), Wardha has developed a low cost biogas plant which resembles an earthen ware pot namely "SURAHI". The mud jars of 300 liter capacity connected

in series is estimated to provide biogas for the cooking need of a family of 4 to 5 at a stretch. They cost only Rs. 650 which is less than one fourth of the traditional masonry built biogas plant. In this design, a pot attached to the first mud jar acts as an inlet for feeding. Similarly, the last jar is attached to another pot for discharge. These two pots are kept above the ground level, and 3/4 th height of each of the mud jars is embedded in the ground. In order to prevent the seepage of the gas through the wall of the jars, they are painted with either a rubber solution or coal tar (Jagadeesh and Devi, 1983).

This centre has proposes to collect the gas in cheep, light, and leak proof balloons. This mud jar biogas plant seems to have great potential specially in areas with good soils.

7. TERI MODELS: --

Tata Energy Research Institute (TERI), New delhi has been involved in constructing fixed dome plants for several years and has developed certain improved designs including a biogas plant design using an of exactly spherical dome (Ramanet al., 1992). The plants constructed have zero failure rate. TERI has developed three models namely TERI Marks I,II, and Mark III with design mean Hydraulic retention time (HRT) of 50 days (Kishore et al, 1987).

TERI Mark I is made of cylindrical digester of brick masonry with spherical segment of dome made by bamboo supporting method. The RCC foundation is provided to prevent possible sinking and consequent wall cracks. both inlets and outlets are located at the same level, but below the ground. They are connected to the

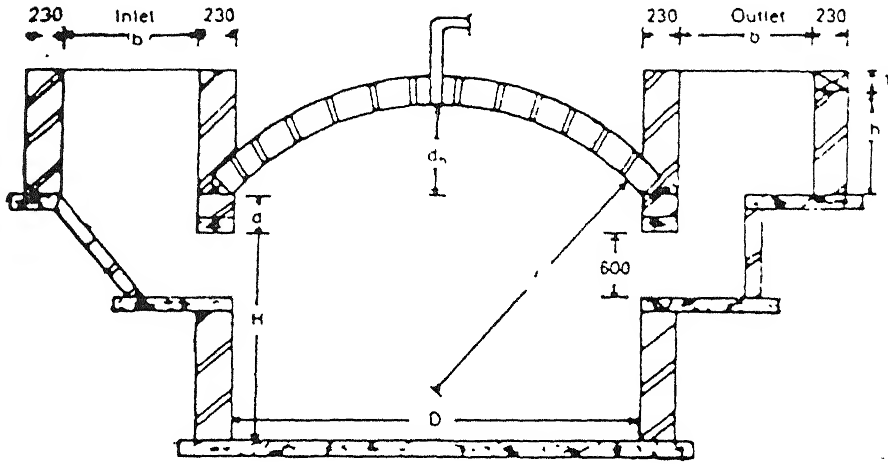


Fig.2.10 TERI Mark I Biogas Plant

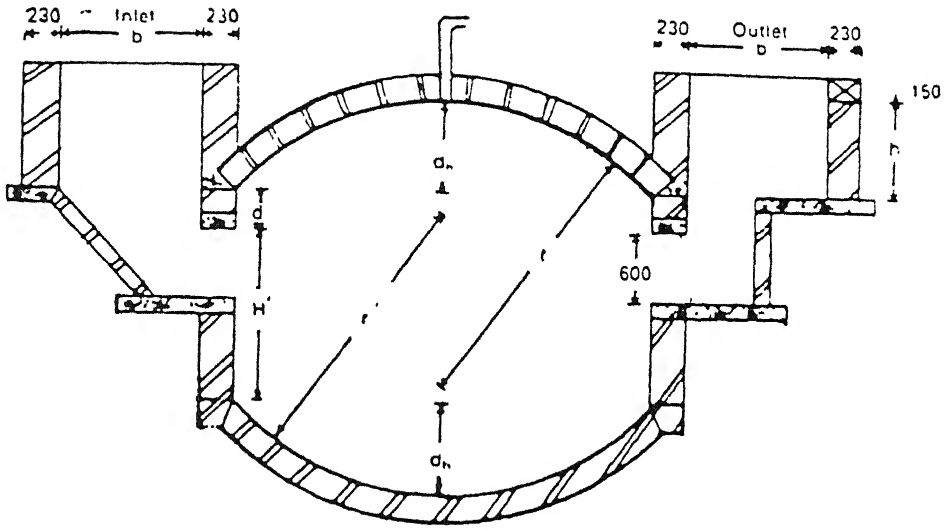


Fig.2.11 TERI Mark II Biogas Plant

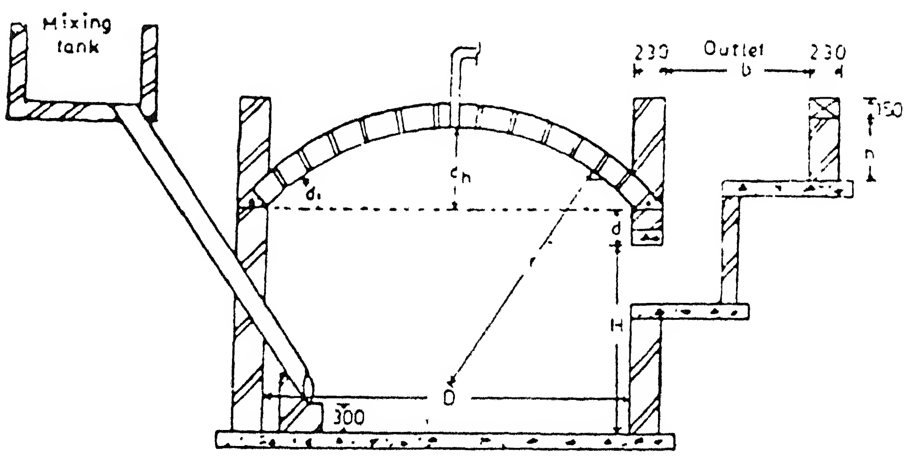


Fig.2.12 TERI Mark III Biogas Plant

digester as shown in Fig. 2.10. Relevant dimensions of this model are given in Table 2.5.

Table 2.5

Dimensional Details of TERI Mark I Biogas Plant

| G ($m^3$/day) | H (m) | D (m) | d (m) | h (m) | b (m) | l (m) | $d_h$ (m) | r (m) |
|---|---|---|---|---|---|---|---|---|
| 2.0 | 1.168 | 2.335 | 0.187 | 0.663 | 0.634 | 0.951 | 0.524 | 1.562 |
| 3.0 | 1.336 | 2.673 | 0.214 | 0.636 | 0.793 | 1.189 | 0.600 | 1.787 |

TERI Mark II has a spherical digester bottom and is constructed with bricks , eliminating the need for the RCC foundation and, hence provides the uniform load and reduces the chances of cracks . It is less costlier than the Mark I (see Fig. 2.11). Relevant dimensions of this model are given in Table 2.6.

Table 2.6

Dimensional Details of TERI Mark II Biogas Plant

| G ($m^3$/day) | H (m) | D (m) | d (m) | h (m) | b (m) | l (m) | $d_h$ (m) | r (m) |
|---|---|---|---|---|---|---|---|---|
| 2.0 | 0.887 | 2.335 | 0.187 | 0.663 | 0.634 | 0.951 | 0.524 | 1.562 |
| 3.0 | 1.016 | 2.673 | 0.214 | 0.636 | 0.793 | 1.189 | 0.600 | 1.787 |

TERI Mark III is similar in shape to Mark I. The only difference is that the inlet tank is replaced by a inlet pipe, and brick tiles are provided in the reinforced dome. A nylon net is provided in this model (Mark III) as a scum breaker which

increases the gas yield upto 12%. Relevant dimensions of this model are given in Table 2.7 (Raman et al., 1992).

Table 2.7

Dimensional Details of TERI Mark III Biogas Plant

| G ($m^3$/day) | H (m) | D (m) | d (m) | $d_1$ (m) | h (m) | b (m) | l (m) | $d_h$ (m) | r (m) |
|---|---|---|---|---|---|---|---|---|---|
| 2.0 | 1.168 | 2.335 | 0.093 | 0.095 | 0.663 | 0.897 | 1.345 | 1.162 | 1.561 |
| 3.0 | 1.336 | 2.673 | 0.107 | 0.111 | 0.636 | 1.121 | 1.6820 | 0.601 | 1.787 |

TERI has also analyzed the heating of the slurry in Mark I by greenhouse heating. They have also experimented to simulate actual flow conditions in biogas digesters using dung slurryto determine residence time distribution and average residence time and have compared it with the HRT conventionally used for designing the biogas digesters (Raman et al., TERI).

Comparative features of some of the selected designs of biogas plants namely KVIC, Janata, Deenbadhu, TERI Mark III and IARI models are given in Table 2.8 (Singh et al., 1993)

## 2.4 HIGH RATE ANAEROBIC REACTORS FOR WASTE WATER TREATMENT

Anaerobic waste water treatment is a relatively new technology which uses somewhat different kind of reactors than those that have been used in biogas plants so far. These reactors are also called "Advanced Reactors" or high rate anaerobic reactors. In fact in waste water treatment plant, the main objective remains to purify the polluted water or to separate the

TABLE 2.8

Comparative Features of Selected Indian designs of Biogas Plants

| Plant model<br>Particulars | KVIC | JBP | Deenbandhu | TERI | IARI |
|---|---|---|---|---|---|
| Charging Materials, Mixing Ratio By weight | Cattle dung, Poultry waste 4:5 | Cattle dung 1:1 | Cattle dung 1:1 | Cattle dung 1:1 | Cattle dung 1:1 |
| Environmental factors pH value | 7-8 | 6.8 to 7.2 | Slightlly alkaline | 6.8-7.2 | Not Mentioned |
| Optimum temperature °C | 35 | 35 | 35 | 35 | 35 |
| Operating temp. °C | 16--40 | 15--30 | | | Same as KVIC |
| Retention Time ( days) | 50--55 | 40 | 40 | 50 | 60 |
| Organic loading rate | 0.2 Kg/$m^3$of digester vol | 3.75 Kg/$m^3$ of gas vol | | 25 Kg of dung/$m^3$of gas vol. | 3.4 Kg/$m^3$of digester vol |
| Gas yield ( on an yearly average basis for 2 m plant capacity | 0.158 $m^3$/kg dry dung | 0.3 $m^3$/ $m^3$ of digester volume | 0.42 $m^3$/ $m^3$ of digester volume. | 0.284 $m^3$/ $m^3$ of diges. volume | 0.158 $m^3$/kg dry dung |
| Cost ( Rupees) | 2840.0 (1981) | 3930.0 (1987) | 3650.0 (1987) | 4510.0 (1987) | less then KVIC by 10% |
| Mixing & Feeding | Manually & Daily | Manually & Daily | Manually & Daily | Manually & Daily | Manually & Daily |
| Scum Breaking Device | Rotation of Gas Holder | No stirrer | No stirre | Nylon net | Rotation of Gas Holder |
| Cleaning & Maintenance | Painting once a year and then after 3 to 4 years | Inside dome Painting in begining & cleaning once in 10 -15yrs | Same as JBP Model | Same as JBP Model | Painting once a year and then after 3 to 4 years |

organic wastes which are suspended in the polluted water, and secondary purpose becomes to decompose the organic waste anaerobically and get the biogas that can be utilized for some useful purposes (Iza et al., 1991).

The concept of high rate anaerobic reactors is based on three fundamental aspects:

(a) The accumulation of biomass within the reactor by means of settling, attachment to the solids (fixed or mobile) or by recirculation. Such systems allow the retention of slowly growing micro-organisms by ensuring that the mean solid retention time (SRT) becomes much longer than the mean HRT.

(b) Improving the contact between biomass and waste water, and overcoming problems of diffusion of substrates and products from the bulk liquids to biofilms or granules.

c) Enhanced activity of the biomass due to adaptation and growth.

The reactor designs developed to implement this technology based on these concepts are depicted by the following reactor blocks (see Fig. 2.13).

I. **Contact reactor:** This reactor is also referred to as the anaerobic activated sludge process reactor. In this system, the suspended biomass is separated by floatation , settlement or filtration by an external gravity or centrifugal separating device and then returned to the digester. And proper mixing is needed.

II. **Anaerobic Filter Reactor (AF):** In this system an inert support material in the form of sheet, ring, or sphere is

arranged and packed in loose fill (randomly packed) or ordered (modular) configuration, which provides extra surface for microbial attachment in stable biofilm form. The reactor may be operated in up or down flow feed mode. It is also known as fixed bed reactor or packed bed reactor.

III. **Downflow Stationary Fixed Film Reactor (DSFF):** It is a type of filter reactor. In this design the oriented support material provides a surface for biofilm formation and leaves open channel for gas release and suspended solids settlement.

IV. **Upflow Anaerobic Sludge Blanket Reactor (UASB):** In this reactor the process relies on the tendency of anaerobic bacteria to form flocs or granules that are retained within the reactor by an efficient gas/liquid/solid separation device located at the top of the reactor . With some waste water, the retained biomass develops into a highly granular sludge with excellent settling properties and forms a sludge bed ( and some times a blanket) within the reactor. In this the even distribution of the influent is required. Good treatment is possible with non granular (flocculant) sludge.

V. **Fluidized Bed Reactor (FB):** In this reactor fine carrier particles are included to retain the biomass by attachment to the carrier surfaces. The attached biofilms with their particles are fluidized with high upflow liquid velocities which are generally produced by combination of influent and

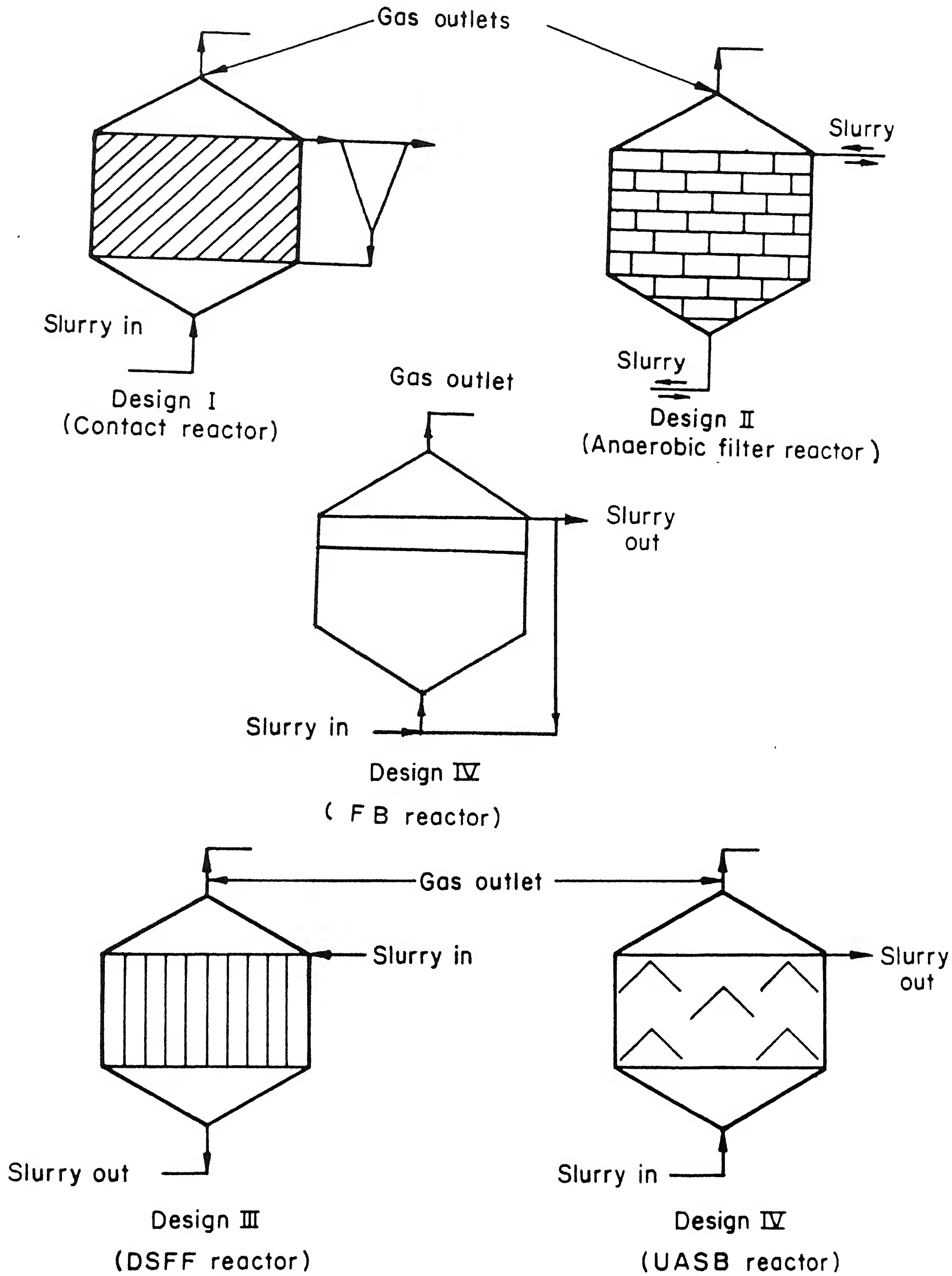


Fig.2.13 Advanced Reactors Designs

recirculation flow rates. The rate of liquid flow and the resultant degree of expansion of bed determines whether the reactor should be termed as a fluidized bed or an expanded bed reactor.

VI. **Hybrid Reactor:** Hybrid reactor can be described as the combination of the above types.

Although in waste water treatment, the anaerobic digestion of the organic waste is generation of biogas as a secondry purpose, but the idea of using these reactors may be tried to reduce HRT for the design of biogas plants (singh et al., 1993).

## 2.5 GENERAL PROBLEMS IN THE ADOPTION OF BIOGAS TECHNOLOGY

If one looks at the potential of biogas as an energy source, one can easily appreciate the fact that it can be a very significant augmenting source of energy. Countries like China have shown it accordingly. Preceding paragraphs have discussed a large number of biogas plant designs and one may just wonder why biogas has not been used as an effective source of energy despite its great potential.

In fact there are many problems associated with the adoption of this technology namely motivational, financial, sociological and technical which are mentioned below briefly (Gobar Gas Why & How, 1984).

1. **Motivational problems** refer to the fact that the people particularly in rural area are not educated about this technology. In fact no serious enough efforts have been made by the government and the non-government agencies in

this directions (Kishore et al., TERI)

2. **Financial problems** refer to the availability of finances for investing in a biogas plant. A common villager may not have sufficient finances to set up a biogas plant in his own backyard.

3. **Sociological problems** refer to the fact that majority of the villagers in a particular village may be poor while few of them may well rich too. The poor may not be able to afford a biogas plant while the rich people can have them in their backyard. The possible solution may be a community biogas plant but even these could not be so far popular due to ownership rights, non existing structure of gas and manure distribution, maintenance problems etc. See detailed account of the problems in Kant, (1981).

4. **Technical problems** refer to the maintenance and operational problems in biogas plants given below:

   a. Corrosion of gas holder in floating drum designs.

   b. Cracking of concrete dome in fixed dome type designs.

   c. Leakage of slurry from the digester into the ground.

   d. Choking of gas pipe line, slurry inlet and outlet.

   e. Settlement of the soil and stones at the bottom of the digester. This may decrease the effective volume of the digester.

   f. Environmental factors like variation in temp., pH value, C/N ratio etc. of the slurry. These may considerably affect the gas yield.

# CHAPTER THREE

# EXPERIMENTAL STUDIES

## 3.1 INTRODUCTION:--

Experimentals were conducted on the so called "Advanced Reactors" to measure the gas yield for a given slurry concentration with different media in the reactors for two values of hydraulic retention times (HRT).

## 3.2 EXPERIMENTAL SET - UP:--

The whole experimental set up consisted of five individual units for five different cases. Each set used a spherical flask of 2 litre capacity made of Pyrex glass as the reactor having an air tight cork carrying two tubes through two holes in it. One tube with an I.D. of 26 mm and made of glass was used for charging the slurry. Another tube of hard plastic of 3 mm. I.D. was used for gas outlet which was attached to a rubber tube. Each unit also had one bottle A as a gas holder, initially filled with brine solution and another calibrated bottle B connected to it through rubber tube to store the displaced brine solution ( see Fig 3.1).

This whole system consisting of the reactor and the gas holder was a closed system. The system was properly sealed and there was no chance for the gas to leak outside or the atmospheric air to enter into the system. A Tee-joint was provided in the gas exit tube connected to the gas holder (bottle A). The purpose of

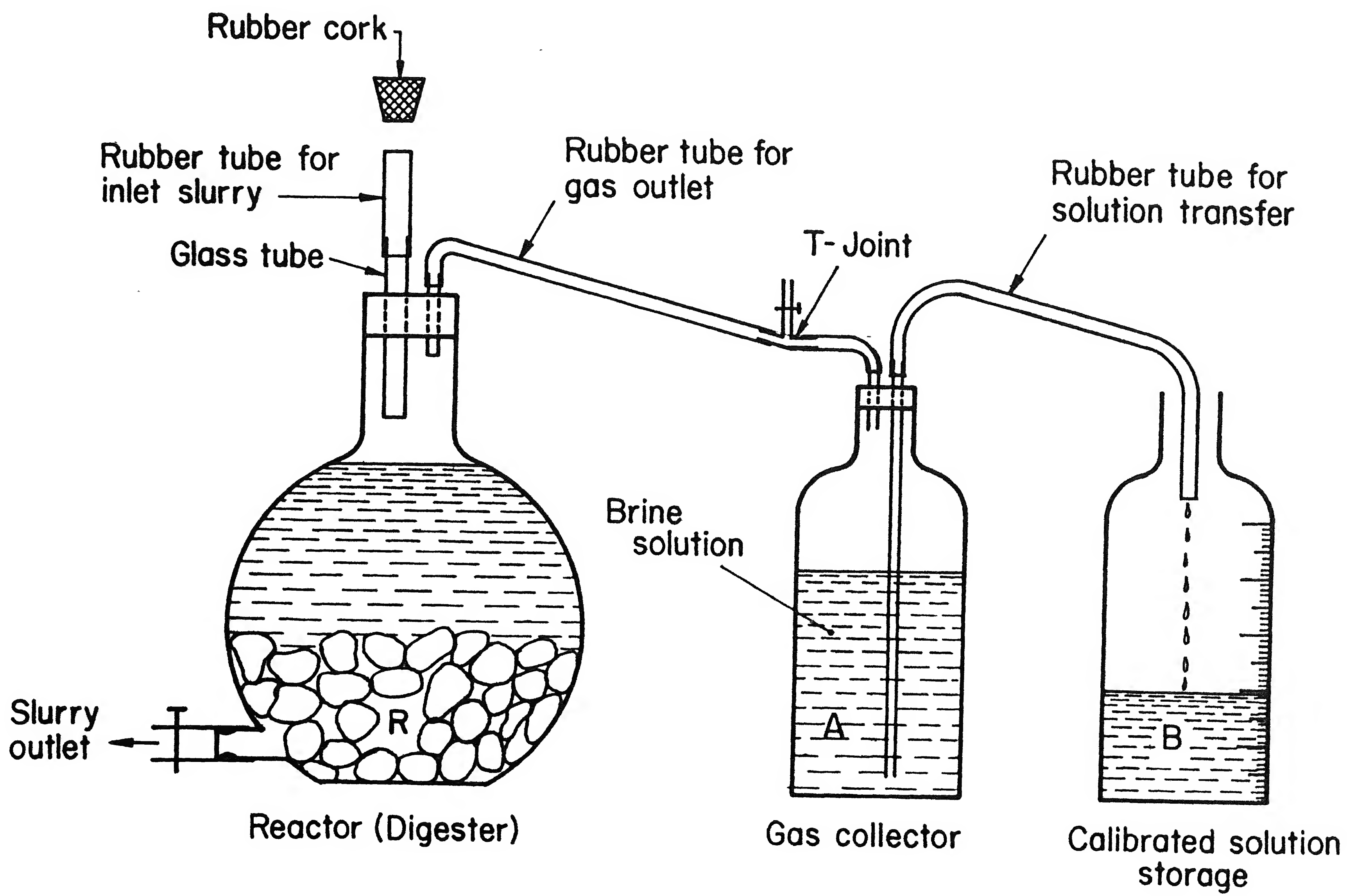


Fig.3.1 Schemetic diagram of the experimental set-up

this Tee was to discharge the gas collected into the atmosphere and refill the bottle A by the brine solution (see Fig. 3.1). The details of the individual units were as follows:

Reactor 1 (R-1):--

The main features of this reactor were same as those of the reactors generally used in real applications with few standard constraints like controlled temperature, pH value etc.. This reactor had a slurry of cow dung and water in the ratio of 1:1 without using any media generally referred to as suspended type of slurry.

Reactor 2 (R-2):--

This reactor was also a suspended type, but cow dung to water ratio in the slurry was 1:5. This lower concentration was used to reveal a rough correlation between gas yield and mixing ratio of cow dung to water. The other conditions taken for this reactor were same as those for R-1.

Reactor 3 (R-3):--

This reactor also had slurry of cow dung to water in the ratio of 1:5, but it functioned with an additional surface area by providing an inert media of plastic pieces for microbial attachment. Surface area of one piece of plastic =24. sq cm

Volume of one piece of plastic =1.387 cu cm

Total volume of the plastic provided in the reactor R-1 = 125 c.c.

$$\therefore \text{ Additional surface area provided } = \frac{24.0}{1.387} \times 125 \text{ sq.cm.}$$
$$\cong .2170 \text{ sq. m.}$$

Reactor 4 (R-4):--

This reactor also had a similar slurry mix as in R-3 , but in this the media consisted of PVC tube pieces generally used in conduit electrical wiring having an average length of 2.1 cm.

Surface area of a piece of this plastic = 22.5 sq cm

Volume of a piece of this plastic = 1.744 cu cm

Total volume of the plastic provided in the reactor = 115 cu cm

$$\therefore \text{ Additional surface area provided in R-4} = \frac{22.5}{1.744} * 115 \text{ sq.cm.} \cong .1185 \text{ sq.m.}$$

**Reactor 5 (R-5):--**

This Reactor again had the same slurry mix of 1:5, but the media used in this rector was stone pieces.

Approximate surface area of an average stone piece =28 sq cm

Approximate volume of an average stone piece =9.508 cu cm

Total volume of stone pieces provided in the reactor is 440 cu cm

$$\therefore \text{ Additional surface area provided} = \frac{440 \times 27.78}{9.508} \text{ sq.cm} \cong .1285 \text{sq.m.}$$

## 3.3 ACCESSORIES AND INSTRUMENTATION:---

Four accessories namely a constant temperature chamber, a pH meter, an oven and a furnace were used which are described below:

### 3.3.1 Constant Temperature Chamber:--

All five reactors R-1 through R-5 were placed in a temperature control chamber and maintained at 35 $^{o}$C with an accuracy of $\pm$ 1$^{o}$C. This temperature was chosen as it is the optimum temperature for the microbial growth.

**3.3.2 pH Meter:--**

The pH value of the slurry was measured using a pH meter directly. It was maintained within the range 6.8 to 7.2 for optimum gas production. Before measuring the pH value of the effluent, the pH meter was kept on for some time to warm it up. The pH meter was standardized in a buffer solution of pH = 9.2.

**3.3.3 Electric Oven:--**

An oven of 0 to 300$^{o}$C temperature range was used for drying the samples at 104$^{o}$C ± 1$^{o}$C.

**3.3.4 Furnace :--**

A furnace was fabricated by wrapping a filament rope on a ceramic tube of internal diameter 60 mm, thickness 10 mm and length 300 mm. The asbestos rope was used to provide the insulation. This whole assembly carrying the ceramic tube was kept in a rectangular GI chamber. The maximum temperature attained by this furnace at the center of the tube was measured by a Chromel Alumel thermocouple. Which was close to 750$^{o}$C. The temperature was maintained at about 550 ± 50$^{o}$C. using a Variac.

**3.4.. PROCEDURE:--**

The procedure consisted of the initial charging followed by daily feeding of the reactors and regulations of the other parameters.

Initial charging was made according to the capacity of the various reactors. The slurry of cow dung and water in the ratio of 1:1 was prepared by mixing 1.0 kg of cow dung in one litre of water for reactor R-1 of 2 litre capacity. For the reactors R-2,

R-3, R-4, and R-5, slurry of cow dung and water in the ratio of 1:5 was prepared. Reactors R-2, R-3 and R-4 had the capacity of 2 litre each, but reactor R-5 had the capacity of only 1.8 litre because in this quite a bit of space was occupied by the solid stone pieces ( used as a media for anaerobic attachment). For these reasons the loading in the reactors R-2, R-3 and R-4 was 333 g of cow dung and that in the reactor R-5 was 300 g.

For daily feeding, first of all a retention period of 10 days was chosen and accordingly one tenth part of the whole slurry was discharged and the same amount of the fresh slurry was fed daily to all the reactors. After getting steady state or stable condition, the experiment was also conducted with 3 days hydraulic retention time. In this case, one third of the slurry was discharged and the same amount of the fresh slurry was fed daily until the stabilization of the reactors. The steady state or the stable condition of the reactor referred to a constant value of gas production per unit quantity of VS consumed. As the pressure of the gas was built up above the slurry in the reactor, the gas was transferred into the bottle A. The Tee-joint was kept clamped for the whole 24 hours. Due to the increased pressure of the gas above the surface of the brine solution, it (brine) got transferred into the other solution storage bottle B ( calibrated bottle) Hence after every 24 hours, the volume of the displaced brine solution measured directly from the bottle B gave the volume of gas produced in a day.

Daily feeding was done for HRT of 10 days. This implied

theoretically that whole slurry was changed in 10 days. Accordingly , one tenth of the total slurry was fed and also discharged daily i.e. 200 ml for the reactors R-1 thru' R-4 and 180 ml. for reactor R-5. During the feeding and discharging of slurry, Tee-joint clamps were kept open so that the air could get into the system for easy discharge of the spent slurry and come out during charging. Now for refilling gas storage A bottles rolling pinch clamps fixed in the gas exit line of the reactors were kept closed and Tee clamps were kept open. The 'A' bottles were refilled by the displaced brine solution. Following this the pinch clamps of Tee joints were closed tightly and rolling clamps were opened. All the individual units (Reactors with Bottles A and B) were then kept into the temperature control chamber for the proper functioning.

The samples of the influent and effluent from each of the reactors were taken and their pH was measured. They then were dried at $104^{o}C \pm 1^{o}C$ for about 12 hours in an oven and then were ignited at $550^{o}C \pm 50^{o}C$ in a furnace for the determination of the volatile solids.

## 3.5. MEASUREMENTS MADE:--

The measurements of the relevant quantities were made as per the procedure described above. The analysis of the experimental data consisted of the following.

### 3.5.1. pH Value Regulation:--

Regulation of pH value was done by measuring the pH value of the effluent. If the pH value was less then 6.8, the medium was

acidic which was not favorable for the microbial growth and hence saturated solution of Sodium bicarbonate was added to make the medium alkaline. Each 10 ml of sodium bicarbonate solution increased the pH value by approximately 0.3 of the slurry of the cow dung and water mixed in the ratio of 1:5. If pH value went up beyond 7.2, it was reduced by adding dilute hydrochloric acid.

**3.5.2 Evaluation of Volatile Solids:--**

First of all to know the volatile solids, one has to know the 'total solids' and 'fixed solids. The term "Total solids" refers to the material left in the vessel after evaporation of the sample and its subsequent drying in a oven at a specified temperature, $104^{\circ}C \pm 1^{\circ}C$ for 12 hours until its mass becomes constant. The total solids include total suspended solids and total dissolves solids. The term "Fixed solids" refers to the residue of the total , suspended, or dissolved solids left after ignition at a specified temperature and specified time ($550 \pm 50^{\circ}C$ for 1 hour). The loss in the mass on ignition refers to "Volatile solids" ( Rand et al., APHA).

In order to determine the Volatile Solids (VS), samples of 5 ml each were taken in quartz dishes and put into an oven at $104 \pm 1^{\circ}C$ for 12 hours to dry them and then weighed. Let the mass of each of the dishes along with dried sample be indicated by x (grams). Each of quartz dishes along with the dried mass was then put into a furnace at $550 \pm 50^{\circ}C$ for an hour, and then weighed again. Let this mass be y grams.

Therefore

$$\text{Volatile solids per liter} = \frac{(x - y) \times 1000}{\text{Volume of the sample in ml.}}$$

5 ml.

$$\text{V.S.} \quad = 200\ (x - y) \qquad g/l$$

**3.5.3 Measurement of Gas yield:--**

The gas coming out of the reactors was measured directly by noting the volume of displaced brine solution into calibrated bottles 'B' (see Fig.3.1) separately. The composition of the gas produced depends upon the material used for fermentation. On an average from cattle dung, the gas consists of 55 to 60 percent methane and 40 to 45 percent carbon dioxide with negligible amount of hydrogen sulfide hydrogen etc.. During the current experimental studies, only cattle dung was used as substrate.

**3.5.4 Analysis of the Biogas:--**

Biogas was analyzed to get a rough idea of the methane content in it. The biogas obtained from the different reactors was analysed by two methods independently, firstly by passing the biogas through 4N KOH solution and secondly by gas chromatograph (AIMIL NUCON). The results are given in the Table 4.4.

**3.5.5 Determination of Chemical Oxygen Demand (COD):--**

Conceptually COD is the oxygen needed by the organic matters from the dissolved oxygen and/or from the water molecules to oxidized and convert the VS into acids and then finally into gases. COD determination provides a measure of the oxygen equivalent of that portion of the organic matter in a sample that

is susceptible to oxidation by a strong oxidant . The 'Dichromate Reflux Method' was selected for COD determination because dichromate is advantageous over other oxidants in oxidizability and applicability to a wide variety of the samples and ease of manipulation. The test finds major usefulness in the plant for waste control purposes (Rand et al., APHA).

**Principle:** Most types of organic matter is destroyed by a boiling mixture of chromic and sulfuric acids. A sample is refluxed with a known amount of potassium dichromate and sulfuric acid and the excess dichromate is titrated with ferrous ammonium sulfate (FAS).

A diluted sample of 2 ml was taken and mixed with 3.5 ml of concentrated sulfuric acid, 1.5 ml of potassium dichromate and 0.5 ml of distilled water and the mixture was kept at 150$^{o}$C for about 2 hours and then titrated with ferrous ammonium sulfate using a proper indicator. The amount of oxidizable organic matter (measured as oxygen equivalent) is proportional to the potassium dichromate consumed.

$$\text{Normality of FAS (N)} = \frac{(\text{Normality} \times \text{volume}) \text{ of potassium dichromate}}{\text{volume of FAS}}$$

$$\text{COD} = \frac{(a - b) \times N \times 8000}{\text{volume of sample in ml}} \quad \text{mg/l}$$

where a → volume in ml of FAS needed for blank (distilled water).

b ⇒ volume in ml of FAS needed for sample

N ⇒ normality of FAS

# CHAPTER FOUR

# RESULTS AND DISCUSSION

## 4.1 INTRODUCTION

As discussed in the previous chapter, the experiments were carried out on five reactors for hydraulic retention time (HRT) of ten days and three days. The measurements of the gas yield were started after 5 days of starting the daily feeding of all the reactors. The gas yield data from all the reactors were collected and other parameters namely volatile solids, gas yield per unit mass of volatile solids consumed, increased gas yield per unit additional surface area and chemical oxygen demand were determined.

## 4.2 GAS YIELD

**a. HRT of Ten Days:--**

The gas yield from reactor R-1 was measured for 21 days only from the beginning of experiment and until steady state for all other reactors. The reactor R-1 having a thick slurry of cow dung and water in the ratio of 1:1 was removed due to choking of the gas passage. Although as expected, the gas yield of this reactor was the highest among all the reactors reaching almost 1700 ml/day after 21 days, but further experiments with this had to discontinued. As all other reactors R-2 through R-5 contained

slurry of cow dung and water in the ratio of 1:5, the objective of including R-1 in the first place was to see the effect of dilution on the gas yield. Table 4.1 lists the comple data collected and Fig 4.1 shows a plot of the gas yield data from R-1 vs. time along with those from other reactors. A magnified view of the data from R-2 through R-5 are given in Fig.4.2. The variation in gas yield from R-4 was irrelevant after 22 days of starting its daily feeding. This was because of accidental discharge of the whole slurry from the reactor. Hence this reactor was recharged with fresh slurry, and data recorded as for the other reactors. The data of R-4 after charging the slurry are also given in Table 4.1 and shown in Fig.4.1 and 4.2. Sudden drop in the gas yield on 23$^{rd}$ day can be seen from Fig. 4.1 and 4.2 after which it starts building up again.

Gas yield from R-2 and R-5 was pretty close to each other. This was because the reactor R-5 had stone pieces as a packing media which was pretty heavy. The biomass in the reactor, therefore, could not be stirred and the surface area of the media (stone pieces) could not be used effectively for the microbial attachment. The fluctuations in Figs. 4.1 and 4.2 can be attributed to the power failure, variation in pH and variation in the quality of the feed.

Table 4.1

Daily Experimental Data and Results from Reactors for Ten Days of HRT

| DATE | REACTOR | pH Value at Room Temp. | Gas Yield | Volatile Solids (g/l) | | | Gas Yield (ml) per unit | | Increased Gas yield per unit Additional Surface Area |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Weight of 5 ml sample | | Volatile Solids in a litre 200(x-y) | VS of Slurry out | VS Consumed | |
| | | | | Dried at 104°C x | Ignited at 550°C y | | | | |
| | | | (ml) | (g) | (g) | (g/l) | (g/l) | (g/l) | (ml/ $m^2$) |
| 22..12..93 | R 1 | 7.02 | 295 | 4.21 | 3.99 | 44 | 6.7 | * | ** |
| | R-2 | 7.02 | 20 | 3.66 | 3.64 | 4 | 5.0 | * | 00 |
| | R-3 | 7.30 | 15 | 3.68 | 3.62 | 12 | 1.25 | * | ** |
| | R-4 | 7.36 | 55 | 3.74 | 3.70 | 8 | 6.87 | * | 295.36 |
| | R-5 | 7.03 | 10 | 3.76 | 3.68 | 16 | 0.62 | * | 17.28 |
| 23..12..93 | R-1 | * | 530 | 4.23 | 3.98 | 50 | 10.6 | * | ** |
| | R-2 | * | 35 | 3.66 | 3.64 | 4 | 8.75 | * | 00 |
| | R-3 | * | 30 | 3.65 | 3.61 | 8 | 3.75 | * | ** |
| | R-4 | * | 110 | 3.70 | 3.62 | 16 | 6.87 | * | 632.9 |
| | R-5 | * | 50 | 3.82 | 3.72 | 20 | 2.50 | * | 246.42 |
| 24..12..93 | R-1 | 6.97 | 700 | 4.23 | 3.99 | 48 | 14.58 | * | ** |
| | R-2 | 7.11 | 20 | 3.68 | 3.64 | 8 | 2.5 | * | 00 |
| | R-3 | 7.08 | 35 | 3.70 | 3.65 | 10 | 3.5 | * | 69.12 |
| | R-4 | 7.01 | 70 | 3.72 | 3.67 | 10 | 7.0 | * | 421.9 |
| | R-5 | 6.99 | 45 | 3.78 | 3.67 | 22 | 2.04 | * | 319.8 |
| 25..12..93 | R-1 | * | 690 | 4.22 | 3.99 | 46 | 15.0 | * | ** |
| | R-2 | * | 40 | 3.66 | 3.64 | 4 | 10 | * | 00 |
| | R-3 | * | 45 | 3.70 | 3.66 | 8 | 5.62 | * | 23.04 |
| | R-4 | * | 35 | 3.73 | 3.68 | 10 | 3.5 | * | ** |
| | R-5 | * | 20 | 3.78 | 3.67 | 22 | .91 | * | ** |

Table 4.1

Daily Experimental Data and Results from Reactors for Ten Days of HRT

| DATE | REACTOR | pH Value at Room Temp. | Gas Yield (ml) | Volatile Solids (g/l): Weight of 5 ml sample: Dried at $104^{o}C$ x (g) | Ignited at $550^{o}C$ y (g) | Volatile Solids in a litre 200(x-y) (g/l) | Gas Yield (ml) per unit: VS of Slurry out (g/l) | VS Consumed (g/l) | Increased Gas yield per unit Additional Surface Area (ml/ $m^2$) |
|---|---|---|---|---|---|---|---|---|---|
| 26.12.93 | R-1 | 7.02 | 715 | 4.20 | 3.99 | 42 | 17.02 | * | ** |
| | R-2 | 7.05 | 50 | 3.66 | 3.63 | 6 | 8.33 | * | 00 |
| | R-3 | 6.70 | 60 | 3.70 | 3.61 | 18 | 3.33 | * | 46.08 |
| | R-4 | 7.02 | 40 | 3.77 | 3.71 | 12 | 3.33 | * | ** |
| | R-5 | 6.97 | 35 | 3.78 | 3.68 | 20 | 1.75 | * | ** |
| 27.12.93 | R-1 | * | 880 | 4.21 | 3.98 | 46 | 19.13 | * | ** |
| | R-2 | * | 100 | 3.70 | 3.65 | 10 | 10.0 | * | 00 |
| | R-3 | * | 110 | 3.71 | 3.65 | 12 | 9.17 | * | 46.08 |
| | R-4 | * | 85 | 3.75 | 3.68 | 14 | 6.07 | * | ** |
| | R-5 | * | 20 | 3.80 | 3.68 | 24 | 0.83 | * | ** |
| 28.12.93 | R-1 | 7.10 | 1170 | -- | -- | -- | -- | * | ** |
| | R-2 | 7.20 | 70 | -- | -- | -- | -- | * | 00 |
| | R-3 | 6.80 | 100 | -- | -- | -- | -- | * | ** |
| | R-4 | 7.02 | 90 | -- | -- | -- | -- | * | ** |
| | R-5 | 7.08 | 10 | -- | -- | -- | -- | * | ** |
| 29.12.93 | R-1 | * | 1030 | 3.98 | 3.76 | 44 | 23.41 | * | ** |
| | R-2 | * | 90 | 3.77 | 3.65 | 24 | 3.75 | * | 00 |
| | R-3 | * | 110 | 3.83 | 3.74 | 18 | 6.11 | * | 92.17 |
| | R-4 | * | 90 | 3.91 | 3.82 | 18 | 5.0 | * | ** |
| | R-5 | * | 25 | 3.92 | 3.82 | 20 | 1.25 | * | ** |

Table 4.1

Daily Experimental Data and Results from Reactors for Ten Days of HRT

| DATE | REACTOR | pH Value at Room Temp. | Gas Yield | Volatile Solids (g/l) | | | Gas Yield (ml) per unit | | Increased Gas yield per unit Additional Surface Area |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Weight of 5 ml sample | | Volatile Solids in a litre 200(x-y) | VS of Slurry out | VS Consumed | |
| | | | | Dried at $104^oC$ x | Ignited at $550^oC$ y | | | | |
| | | | (ml) | (g) | (g) | (g/l) | (g/l) | (g/l) | (ml/ $m^2$) |
| 30..12..93 | R 1 | 6.93 | 1150 | 4.05 | 3.85 | 50 | 23.0 | * | ** |
| | R-2 | 7.02 | 95 | 3.91 | 3.81 | 20 | 4.75 | * | 00 |
| | R-3 | 7.03 | 70 | 3.88 | 3.77 | 22 | 3.18 | * | ** |
| | R-4 | 7.10 | 110 | 3.81 | 3.70 | 22 | 5.0 | * | 126.58 |
| | R-5 | 6.98 | 70 | 3.76 | 3.65 | 22 | 3.18 | * | ** |
| 31..12..93 | R-1 | 7.03 | 1320 | -- | -- | -- | -- | * | ** |
| | R-2 | 6.93 | 90 | -- | -- | -- | -- | * | 00 |
| | R-3 | 7.10 | 70 | -- | -- | -- | -- | * | ** |
| | R-4 | 6.88 | 70 | -- | -- | -- | -- | * | ** |
| | R-5 | 6.98 | 110 | -- | -- | -- | -- | * | 337.04 |
| 1..1..94 | R-1 | * | 1560 | 3.96 | 3.71 | 50 | 31.2 | * | ** |
| | R-2 | * | 110 | 3.99 | 3.88 | 22 | 5.0 | * | 00 |
| | R-3 | * | 60 | 3.90 | 3.80 | 20 | 3.0 | * | ** |
| | R-4 | * | 90 | 3.84 | 3.72 | 24 | 3.75 | * | ** |
| | R-5 | * | 100 | 3.79 | 3.70 | 18 | 5.56 | * | 95.09 |
| 2..1..94 | R-1 | * | 1625 | 3.94 | 3.68 | 52 | 31.25 | * | ** |
| | R-2 | * | 140 | 3.83 | 3.70 | 26 | 5.38 | * | 00 |
| | R-3 | * | 95 | 3.94 | 3.84 | 20 | 4.75 | * | ** |
| | R-4 | * | 100 | 3.85 | 3.69 | 32 | 3.12 | * | ** |
| | R-5 | * | 110 | 3.83 | 3.68 | 30 | 3.67 | * | ** |

Table 4.1

Daily Experimental Data and Results from Reactors for Ten Days of HRT

| DATE | REACTOR | pH Value at Room Temp. | Gas Yield | Volatile Solids (g/l) | | | Gas Yield (ml) per unit | | Increased Gas yield per unit Additional Surface Area |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Weight of 5 ml sample | | Volatile Solids in a litre 200(x-y) | VS of Slurry out | VS Consumed | |
| | | | | Dried at $104^oC$ x | Ignited at $550^oC$ y | | | | |
| | | | (ml) | (g) | (g) | (g/l) | (g/l) | (g/l) | ($ml/m^2$) |
| 3.1.94 | R-1 | * | 1900 | 3.96 | 3.69 | 54 | | * | ** |
| | R-2 | * | 210 | 3.87 | 3.75 | 24 | 8.75 | * | 00 |
| | R-3 | * | 120 | 3.90 | 3.80 | 20 | 6.00 | * | ** |
| | R-4 | * | 175 | 3.87 | 3.73 | 28 | 6.25 | * | ** |
| | R-5 | * | 360 | 3.85 | 3.71 | 28 | 12.85 | * | 1478.2 |
| 4.1.94 | R-1 | 7.18 | 1725 | --- | --- | --- | -- | * | ** |
| | R-2 | 6.56 | 300 | 3.82 | 3.72 | 20 | 15.00 | * | 00 |
| | R-3 | 6.85 | 150 | 4.01 | 3.90 | 22 | 6.82 | * | ** |
| | R-4 | 6.92 | 240 | 3.71 | 3.63 | 16 | 15.0 | * | ** |
| | R-5 | 7.05 | 390 | 3.79 | 3.69 | 20 | 19.5 | * | 1037.2 |
| 5.1.94 | R-1, Influent | 7.11 | 1700 | 3.79 | 3.67 | 24 | * | * | ** |
| | R-2 | 6.6 | 380 | 3.76 | 3.68 | 16 | 23.75 | 47.5 | 00 |
| | R-3 | 6.56 | 170 | 4.06 | 3.92 | 28 | 6.07 | ** | ** |
| | R-4 | 6.74 | 230 | 3.71 | 3.63 | 16 | 14.37 | 28.75 | ** |
| | R-5 | 7.01 | 370 | 3.80 | 3.67 | 26 | 14.23 | ** | ** |
| 6.1.94 | R-1, Influent | 7.08 | 1690 | 3.98 | 3.86 | 24 | * | * | ** |
| | R-2 | 6.90 | 440 | 3.88 | 3.78 | 20 | 22.0 | 110.0 | 00 |
| | R-3 | 6.88 | 370 | 3.92 | 3.81 | 22 | 16.81 | 185.0 | ** |
| | R-4 | 7.06 | 490 | 3.96 | 3.86 | 20 | 24.5 | 122.5 | 421.9 |
| | R-5 | 7.04 | 450 | 3.81 | 3.72 | 18 | 25.0 | 75.0 | 463.03 |

Table 4.1

Daily Experimental Data and Results from Reactors for Ten Days of HRT

| DATE | REACTOR | pH Value at Room Temp. | Gas Yield (ml) | Volatile Solids (g/l) Weight of 5 ml sample: Dried at $104^{o}C$ x (g) | Ignited at $550^{o}C$ y (g) | Volatile Solids in a litre 200(x-y) (g/l) | Gas Yield (ml) per unit: VS of Slurry out (g/l) | VS Consumed (g/l) | Increased Gas yield per unit Additional Surface Area (ml/ $m^2$) |
|---|---|---|---|---|---|---|---|---|---|
| 7..1..9 | Influent | | | 3.96 | 3.84 | 24 | | | |
| | R-2 | * | 420 | 3.89 | 3.79 | 20 | 21.00 | 105.0 | 00 |
| | R-3 | * | 370 | 3.92 | 3.81 | 22 | 16.81 | 185.0 | ** |
| | R-4 | * | 550 | ** | ** | ** | * | 137.5 | 1097.0 |
| | R-5 | * | 400 | 3.92 | 3.82 | 20 | 20.0 | 100.0 | 189.9 |
| 8..1.94 | Influent | 7.20 | | 4.01 | 3.89 | 24 | | | |
| | R-2 | 7.02 | 430 | 3.92 | 3.82 | 20 | 21.5 | 107.5 | 00 |
| | R-3 | 7.01 | 590 | 3.89 | 3.80 | 18 | 32.78 | 98.3 | 184.3 |
| | R-4 | 6.80 | 240 | 3.82 | 3.71 | 22 | 10.9 | 120.0 | ** |
| | R-5 | 6.89 | 390 | 3.83 | 3.73 | 20 | 19.5 | 97.5 | 22.7 |
| 9..1..94 | Influent | 7.22 | | 3.78 | 3.65 | 26 | | | |
| | R-2 | 6.95 | 360 | 3.80 | 3.70 | 20 | 18.0 | 60.0 | 00 |
| | R-3 | 6.87 | 630 | 3.97 | 3.89 | 16 | 39.37 | 63.0 | 1244.2 |
| | R-4 | 7.01 | 320 | 3.71 | 3.61 | 20 | 16.0 | 53.3 | ** |
| | R-5 | 7.03 | 360 | 3.82 | 3.71 | 22 | 16.36 | 90.0 | 308.2 |
| 10..1.94 | Influent | 7.24 | | 3.77 | 3.67 | 24 | | | |
| | R-2 | 6.95 | 380 | 3.82 | 3.72 | 20 | 19.0 | 95.0 | 00 |
| | R-3 | 7.19 | 600 | 4.00 | 3.90 | 20 | 30.0 | 150.0 | 1013.8 |
| | R-4 | 7.21 | 400 | 3.67 | 3.58 | 18 | 22.2 | 66.7 | 168.8 |
| | R-5 | 7.16 | 360 | 3.78 | 3.68 | 20 | 18.0 | 90.0 | 152.5 |

Table 4.1

Daily Experimental Data and Results from Reactors for Ten Days of HRT

| DATE | REACTOR | pH Value at Room Temp. | Gas Yield (ml) | Volatile Solids (g/l): Weight of 5 ml sample: Dried at $104^oC$ x (g) | Ignited at $550^oC$ y (g) | Volatile Solids in a litre 200(x-y) (g/l) | Gas Yield (ml) per unit: VS of Slurry out (g/l) | VS Consumed (g/l) | Increased Gas yield per unit Additional Surface Area (ml/ $m^2$) |
|---|---|---|---|---|---|---|---|---|---|
| 11..1..94 | Influent | 7.18 | | 3.79 | 3.67 | 24 | | | |
| | R-2 | 7.02 | 390 | 3.83 | 3.73 | 20 | 19.5 | 97.5 | 00 |
| | R-3 | 7.11 | 590 | 4.00 | 3.90 | 20 | 29.5 | 147.5 | 921.6 |
| | R-4 | 7.15 | 420 | 3.71 | 3.61 | 18 | 23.3 | 87.7 | 253.2 |
| | R-5 | 7.08 | 380 | 3.76 | 3.66 | 20 | 19.0 | 95.5 | 247.5 |
| 12..1..94 | Influent | 7.30 | | 3.79 | 3.67 | 24 | | | |
| | R-2 | 7.03 | 460 | 3.80 | 3.70 | 20 | 23.0 | 115.0 | 00 |
| | R-3 | 7.08 | 560 | 3.90 | 3.80 | 20 | 28.0 | 140.0 | 460.8 |
| | R-4 | 7.09 | 610 | 3.69 | 3.60 | 18 | 33.8 | 101.7 | 1265.8 |
| | R-5 | 7.10 | 470 | 3.72 | 3.62 | 20 | 23.5 | 117.5 | 480.1 |
| 13..1..94 | Influent | 7.25 | | 3.81 | 3.69 | 24 | | | |
| | R-2 | 6.88 | 460 | 3.79 | 3.69 | 20 | 23.0 | 115.0 | 00 |
| | R-3 | 6.92 | 550 | 3.87 | 3.77 | 20 | 27.5 | 137.5 | 414.7 |
| | R-4 | 6.82 | 630 | 4.02 | 3.93 | 18 | 35.0 | 105.0 | 1434.5 |
| | R-5 | 7.03 | 440 | 3.79 | 3.69 | 20 | 22.0 | 110.0 | 221.0 |
| 14..1..94 | Influent | 7.26 | | 3.98 | 3.86 | 24 | | | |
| | R-2 | 7.02 | 470 | 3.79 | 3.69 | 20 | 23.5 | 117.5 | 00 |
| | R-3 | 7.14 | 580 | 3.88 | 3.78 | 20 | 29.0 | 145.0 | 506.9 |
| | R-4 | 7.06 | 620 | 3.70 | 3.61 | 18 | 34.4 | 103.3 | 1265.8 |
| | R-5 | 7.15 | 450 | 3.71 | 3.61 | 20 | 23.6 | 112.5 | 229.6 |

Table 4.1

Daily Experimental Data and Results from Reactors for Ten Days of HRT

| DATE | REACTOR | pH Value at Room Temp. | Gas Yield (ml) | Volatile Solids (g/l): Weight of 5 ml sample: Dried at 104°C x (g) | Ignited at 550°C y (g) | Volatile Solids in a litre 200(x-y) (g/l) | Gas Yield (ml) per unit: VS of Slurry out (g/l) | VS Consumed (g/l) | Increased Gas yield per unit Additional Surface Area (ml/ $m^2$) |
|---|---|---|---|---|---|---|---|---|---|
| 15..1..94 | Influent | 7.18 | | 3.99 | 3.87 | 24 | | | |
| | R-2 | 7.03 | 460 | 3.81 | 3.71 | 20 | 23.0 | 115.0 | 00 |
| | R-3 | 6.98 | 570 | 3.79 | 3.69 | 20 | 28.5 | 142.5 | 506.9 |
| | R-4 | 7.08 | 620 | 3.72 | 3.63 | 18 | 34.4 | 103.3 | 1350.2 |
| | R-5 | 7.10 | 440 | 3.76 | 3.66 | 20 | 22.0 | 110.0 | 221.0 |
| 16..1..94 | Influent | 7.25 | | 4.02 | 3.89 | 26 | | | |
| | R-2 | 7.21 | 470 | 3.82 | 3.72 | 20 | 23.5 | 117.5 | 00 |
| | R-3 | 7.18 | 600 | 3.80 | 3.70 | 20 | 30.0 | 150.0 | 599.0 |
| | R-4 | 7.03 | 590 | 3.78 | 3.69 | 18 | 32.8 | 98.3 | 1012.6 |
| | R-5 | 7.08 | 400 | 3.79 | 3.69 | 20 | 22.2 | 111.0 | ** |
| 17..1..94 | Influent | 7.23 | | 3.97 | 3.85 | 24 | | | |
| | R-2 | 7.04 | 440 | 3.81 | 3.70 | 22 | 20.0 | 110.0 | 00 |
| | R-3 | 7.04 | 610 | 3.84 | 3.73 | 22 | 27.7 | 152.5 | 783.4 |
| | R-4 | 6.96 | 510 | 3.78 | 3.67 | 22 | 23.2 | 127.5 | 590.7 |
| | R-5 | 7.07 | 410 | 3.76 | 3.65 | 22 | 20.7 | 113.9 | 120.6 |
| 18..1..94 | Influent | 7.30 | | 3.89 | 3.77 | 24 | | | |
| | R-2 | 7.02 | 430 | 3.77 | 3.67 | 20 | 21.5 | 107.5 | 00 |
| | R-3 | 7.08 | 620 | 3.76 | 3.66 | 20 | 31.0 | 155.0 | 875.6 |
| | R-4 | 7.01 | 540 | 3.71 | 3.61 | 20 | 27.0 | 135.0 | 928.3 |
| | R-5 | 7.00 | 400 | 3.76 | 3.66 | 20 | 22.2 | 111.0 | 108.9 |

Table 4.1

Daily Experimental Data and Results from Reactors for Ten Days of HRT

| DATE | REACTOR | pH Value at Room Temp. | Gas Yield (ml) | Volatile Solids (g/l): Weight of 5 ml sample: Dried at 104°C x (g) | Volatile Solids (g/l): Weight of 5 ml sample: Ignited at 550°C y (g) | Volatile Solids (g/l): Volatile Solids in a litre 200(x−y) (g/l) | Gas Yield (ml) per unit: VS of Slurry out (g/l) | Gas Yield (ml) per unit: VS Consumed (g/l) | Increased Gas yield per unit Additional Surface Area (ml/ $m^2$) |
|---|---|---|---|---|---|---|---|---|---|
| 19..1..94 | Influent | 7.24 | | 3.87 | 3.74 | 26 | | | |
| | R-2 | 7.00 | 445 | 3.89 | 3.79 | 20 | 22.2 | 111.2 | 00 |
| | R-3 | 7.03 | 620 | 3.73 | 3.63 | 20 | 31.0 | 155.0 | 806.5 |
| | R-4 | 6.98 | 535 | 3.79 | 3.69 | 20 | 26.7 | 133.2 | 759.4 |
| | R-5 | 6.93 | 400 | 3.71 | 3.61 | 20 | 22.2 | 111.0 | ** |
| 20..1..94 | Influent | 7.24 | | | | | | | |
| | R-2 | 7.03 | 440 | | | | | | 00 |
| | R-3 | 6.98 | 610 | | | | | | 783.4 |
| | R-4 | 7.10 | 540 | | | | | | 843.8 |
| | R-5 | 7.08 | 410 | | | | | | 120.6 |
| 21..1..94 | Influent | 7.20 | | 3.93 | 3.81 | 24 | | | |
| | R-2 | 7.04 | 445 | 3.86 | 3.76 | 20 | 22.2 | 111.2 | 00 |
| | R-3 | 7.03 | 615 | 3.79 | 3.69 | 20 | 30.7 | 153.2 | 783.4 |
| | R-4 | 7.07 | 535 | 3.76 | 3.66 | 20 | 26.7 | 133.3 | 759.5 |
| | R-5 | 7.08 | 410 | 3.78 | 3.68 | 20 | 22.6 | 113.9 | 81.9 |
| 22..1..94 | Influent | 7.28 | | 3.91 | 3.79 | 24 | | | |
| | R-2 | 6.98 | 440 | 3.83 | 3.73 | 20 | 22.0 | 111.0 | 00 |
| | R-3 | 7.03 | 615 | 3.80 | 3.70 | 20 | 30.7 | 153.7 | 806.5 |
| | R-4 | 7.00 | 540 | 3.79 | 3.69 | 20 | 27.0 | 135.0 | 843.9 |
| | R-5 | 6.93 | 410 | 3.71 | 3.61 | 20 | 22.6 | 113.8 | 120.6 |

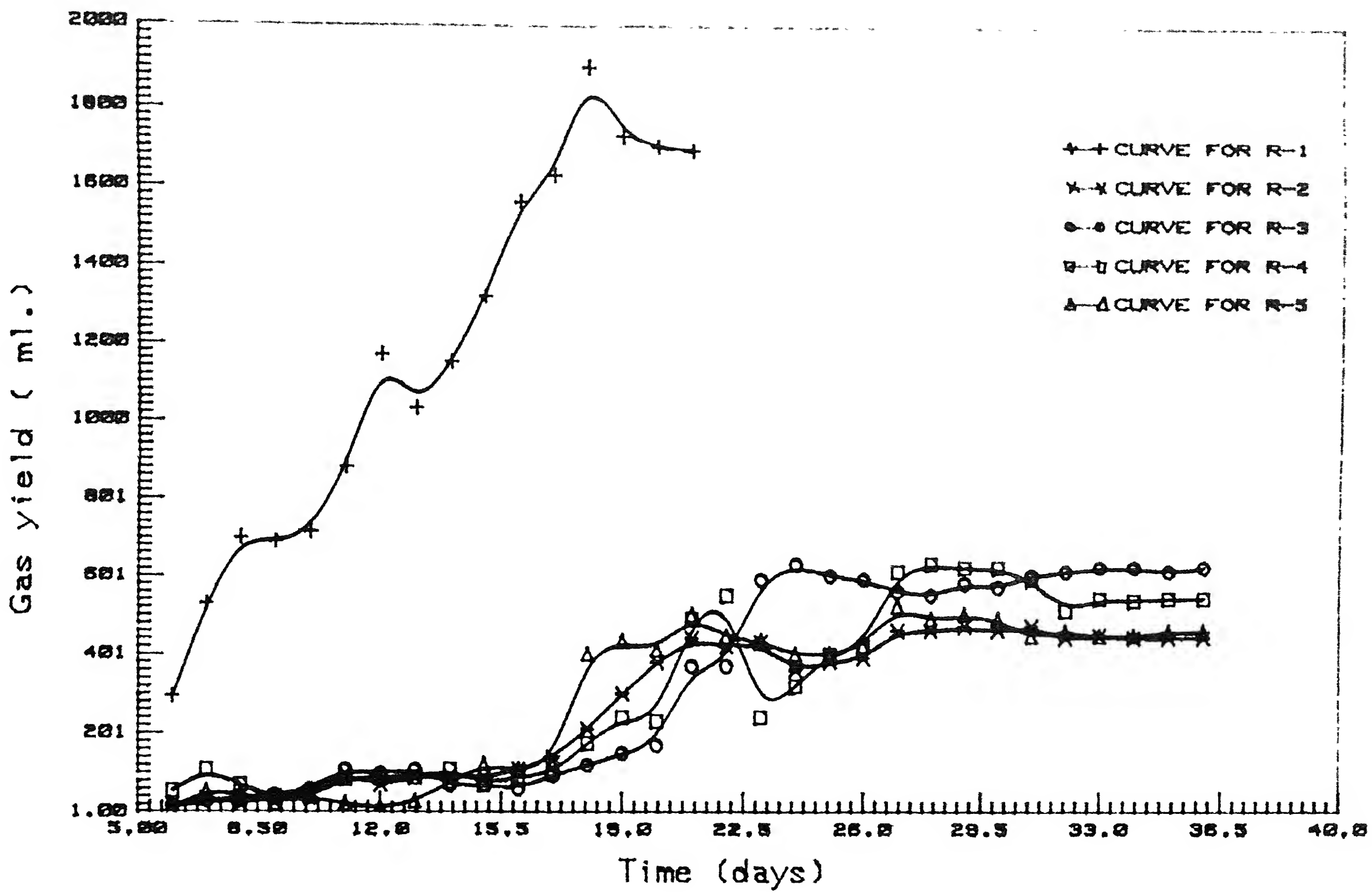


Fig.4.1 Variation of Daily Gas Yield with Time for a HRT of 10 Days for 5 Reactor

Graphstar

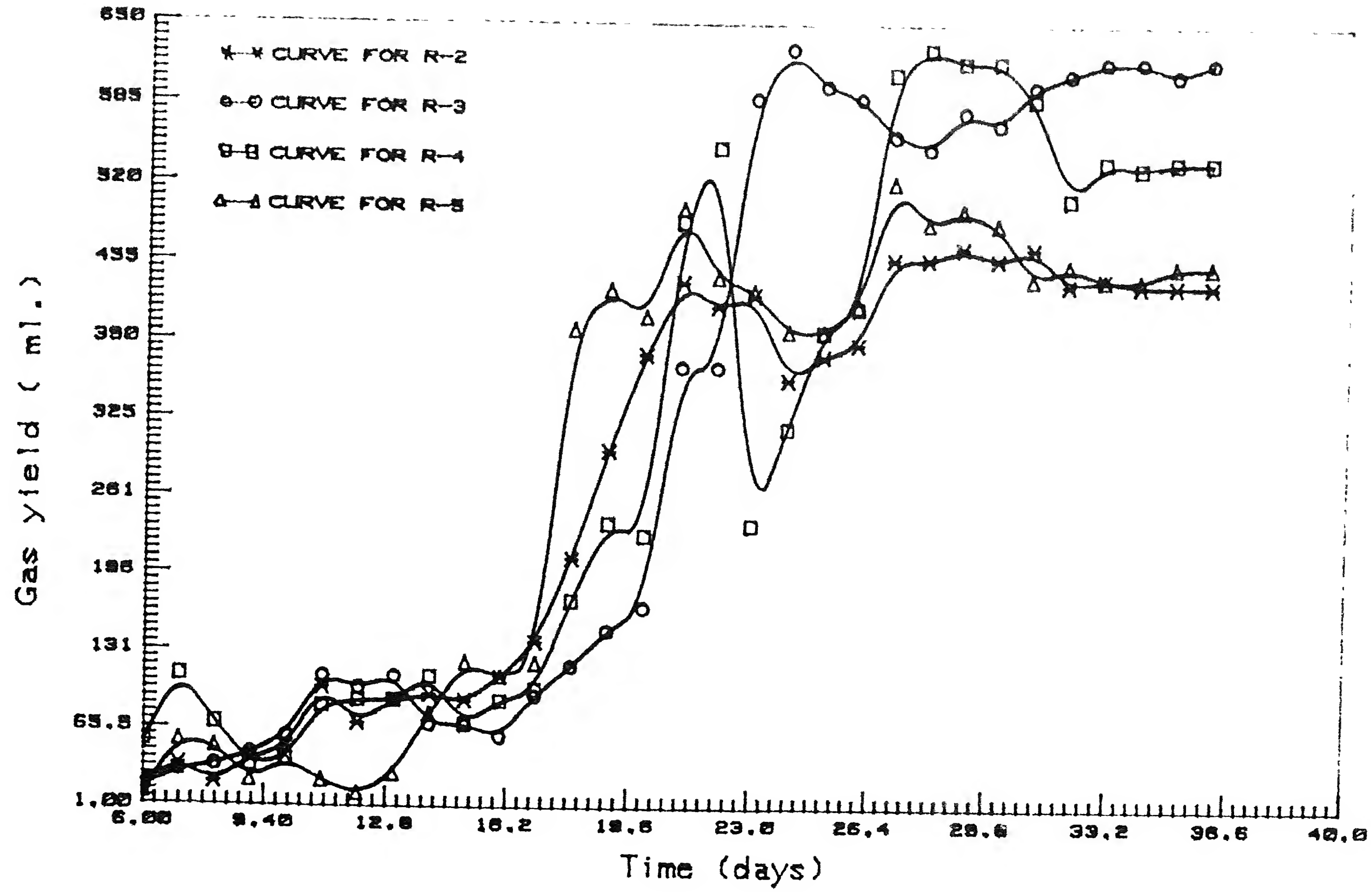


Fig.4.2 Variation of Daily Gas Yield with Time for a HRT of 10 Days for 4 Reactors

Graphstar

* sps * cc-iit/k : vayu * 02/08/94 11:53:15 *

b. HRT of three days:--

Fig. 4.3 shows the gas yield data vs. time for HRT of three days. For these data only reactors R-2 thru' R-5 were used with the same media. The reactor R-3, unfortunately had broken because of some handling problems. Therefore, no data could be recorded with it. Out of the remaining reactors R-2, R-4 and R-5, reactor R-4 in this case gave the highest gas yield, which had PVC tubes as the media. The data for HRT of three days are given in Table 4.2. The fluctuation in the data now were much smaller owing to the favorable environment in which the experiments were started for this HRT.

4.3 VOLATILE SOLIDS IN INFLUENT AND EFFLUENT:--

The volatile solids (VS)of the discharged slurry from the reactors were determined as per the procedure described in section 3.2.

a. HRT of ten days:--

The VS of the influent slurry which was same for all the reactors was also measured. For reactor R-1 it was measured only up to 18 days, but for other reactors it was measured until the steady state was reached. As mentioned above, the data on R-2 had to be discontinued due to choking of the gas passage.

Figures 4.3 and 4.4 show the variation of (VS) of the discharged slurry with time. This value depends upon the quantity of gas produced as well as the VS of the fresh feed (influent).

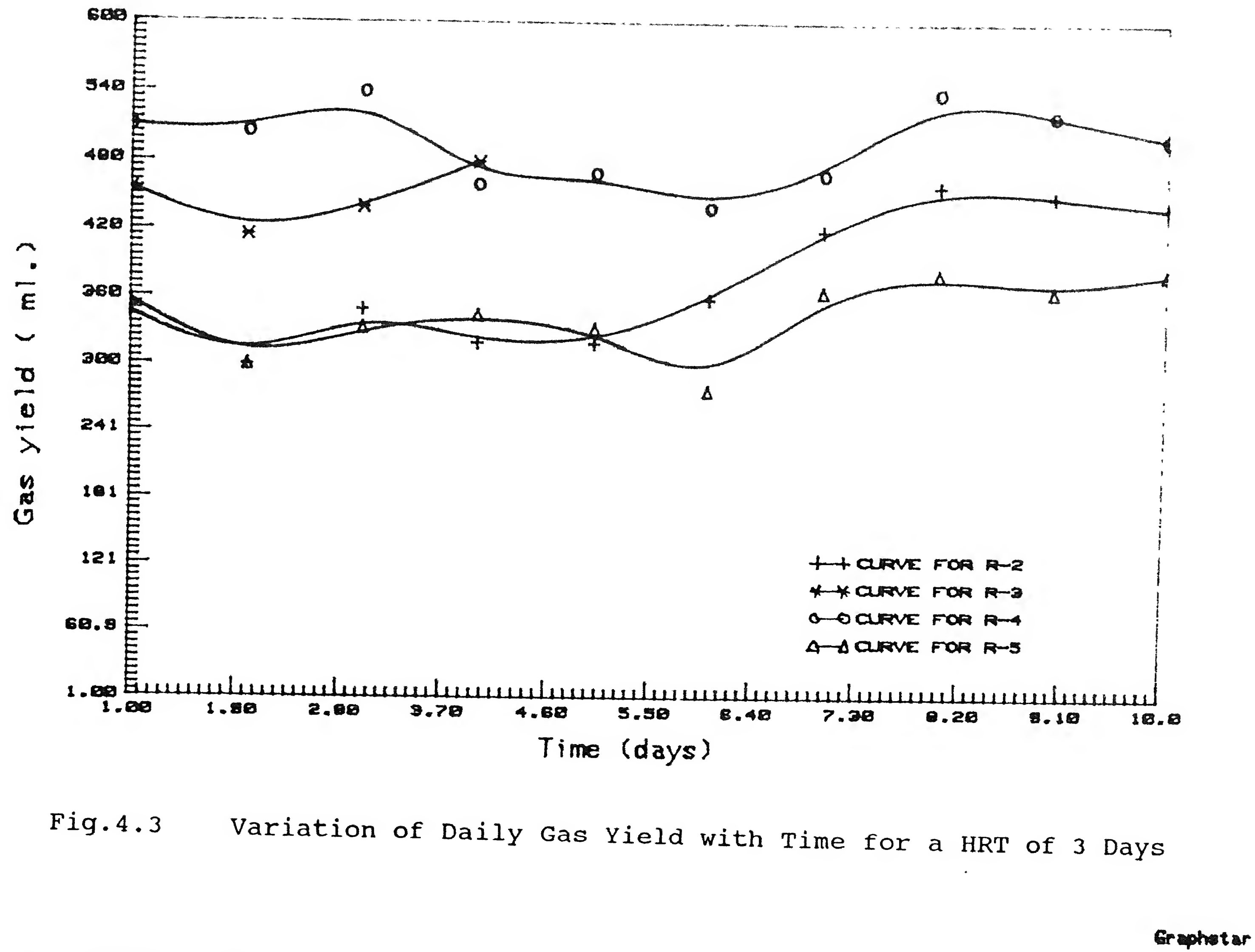


Fig.4.3 Variation of Daily Gas Yield with Time for a HRT of 3 Days

* sps * cc-iit/k : vayu * 02/08/94 11:53:15 *

Table 4.2

Daily Experimental Data and Results from Reactors for Three Days of HRT

| DATE | REACTOR | pH Value at Room Temp. | Gas Yield (ml) | Volatile Solids (g/l): Weight of 5 ml sample: Dried at 104°C x (g) | Ignited at 550°C y (g) | Volatile Solids in a litre 200(x-y) (g/l) | Gas Yield (ml) per unit: VS of Slurry out (g/l) | VS Consumed (g/l) | Increased Gas yield per unit Additional Surface Area (ml/ $m^2$) |
|---|---|---|---|---|---|---|---|---|---|
| 23..1..94 | Influent | 7.22 | | 3.91 | 3.80 | 22 | | | |
| | R-2 | 6.98 | 345 | 3.93 | 3.84 | 18 | 19.2 | 86.2 | 00 |
| | R-3 | 6.86 | 455 | 3.76 | 3.67 | 18 | 25.3 | 113.7 | 46.1 |
| | R-4 | 6.90 | 510 | 3.78 | 3.70 | 16 | 31.9 | 85.0 | 1392.4 |
| | R-5 | 7.00 | 320 | 3.73 | 3.64 | 18 | 19.7 | 88.8 | 120.6 |
| 24..1..94 | Influent | 7.21 | | 3.80 | 3.69 | 24 | | | |
| | R-2 | 7.01 | 300 | 3.75 | 3.66 | 18 | 16.6 | 75.0 | 00 |
| | R-3 | 6.99 | 415 | 3.77 | 3.69 | 16 | 25.9 | 69.2 | 69.1 |
| | R-4 | 6.81 | 505 | 3.71 | 3.62 | 18 | 28.1 | 126.2 | 1729.9 |
| | R-5 | 7.05 | 270 | 3.98 | 3.89 | 18 | 16.7 | 75.0 | ** |
| 25..1..94 | Influent | 7.24 | | 3.96 | 3.84 | 24 | | | |
| | R-2 | 7.00 | 350 | 3.84 | 3.74 | 20 | 17.5 | 87.5 | 00 |
| | R-3 | 7.03 | 440 | 3.81 | 3.71 | 20 | 22.0 | 110.0 | 414.7 |
| | R-4 | 7.00 | 540 | 3.88 | 3.79 | 18 | 30.0 | 90.0 | 1603.4 |
| | R-5 | 6.98 | 300 | 3.71 | 3.60 | 22 | 15.14 | 166.5 | ** |
| 26..1..94 | Influent | 7.20 | | 3.85 | 3.73 | 24 | | | |
| | R-2 | 6.98 | 320 | 3.79 | 3.69 | 20 | 16.0 | 80.0 | 00 |
| | R-3 | 7.03 | 480 | 3.81 | 3.71 | 20 | 24.0 | 120.0 | 737.3 |
| | R-4 | 7.01 | 460 | 3.80 | 3.70 | 20 | 23.0 | 115.0 | 1181.4 |
| | R-5 | 7.08 | 310 | 3.78 | 3.68 | 20 | 17.22 | 86.1 | 194.6 |

Table 4.2

Daily Experimental Data and Results from Reactors for Three Days of HRT

| DATE | REACTOR | pH Value at Room Temp. | Gas Yield (ml) | Volatile Solids (g/l): Weight of 5 ml sample: Dried at 104°C x (g) | Ignited at 550°C y (g) | Volatile Solids in a litre 200(x-y) (g/l) | Gas Yield (ml) per unit: VS of Slurry out (g/l) | VS Consumed (g/l) | Increased Gas yield per unit Additional Surface Area (ml/ $m^2$) |
|---|---|---|---|---|---|---|---|---|---|
| 27..01..94 | Influent | 7.18 | | 3.93 | 3.81 | 24 | | | |
| | R-2 | 6.93 | 320 | 3.78 | 3.68 | 20 | 16.0 | 80.0 | 00 |
| | R-4 | 7.00 | 470 | 3.79 | 3.70 | 18 | 26.1 | 78.3 | 1265.8 |
| | R-5 | 7.01 | 300 | 3.76 | 3.66 | 20 | 16.7 | 83.2 | 103.5 |
| 28..01..94 | Influent | 7.20 | | 3.91 | 3.79 | 24 | | | |
| | R-2 | 7.02 | 360 | 3.76 | 3.66 | 20 | 18.0 | 90.0 | 00 |
| | R-4 | 6.91 | 440 | 3.81 | 3.71 | 20 | 22.0 | 110.0 | 675.1 |
| | R-5 | 7.00 | 250 | 3.79 | 3.68 | 22 | 12.6 | 138.8 | ** |
| 29..01..94 | Influent | 7.20 | | 3.88 | 3.76 | 24 | | | |
| | R-2 | 6.98 | 420 | 3.84 | 3.74 | 20 | 21.0 | 105.0 | 00 |
| | R-4 | 6.98 | 470 | 3.81 | 3,71 | 20 | 23.0 | 117.5 | 421.9 |
| | R-5 | 7.02 | 330 | 3.78 | 3.68 | 20 | 18.3 | 91.6 | ** |
| 30..01..94 | Influent | 7.20 | | 3.96 | 3.84 | 24 | | | |
| | R-2 | 7.03 | 460 | 3.79 | 3.69 | 20 | 23.0 | 115.0 | 00 |
| | R-4 | 7.01 | 540 | 3.81 | 3.71 | 20 | 27.0 | 135.0 | 675.1 |
| | R-5 | 6.98 | 340 | 3.74 | 3.64 | 20 | 19.0 | 95.0 | ** |
| 31..01..94 | Influent | 7.20 | | 3.91 | 3.79 | 24 | | | |
| | R-2 | 6.92 | 450 | 3.80 | 3.70 | 20 | 22.5 | 112.5 | 00 |
| | R-4 | 7.93 | 520 | 3.76 | 3.66 | 20 | 26.0 | 130.0 | 590.7 |
| | R-5 | 6.90 | 330 | 3.72 | 3.62 | 20 | 18.3 | 91.5 | ** |

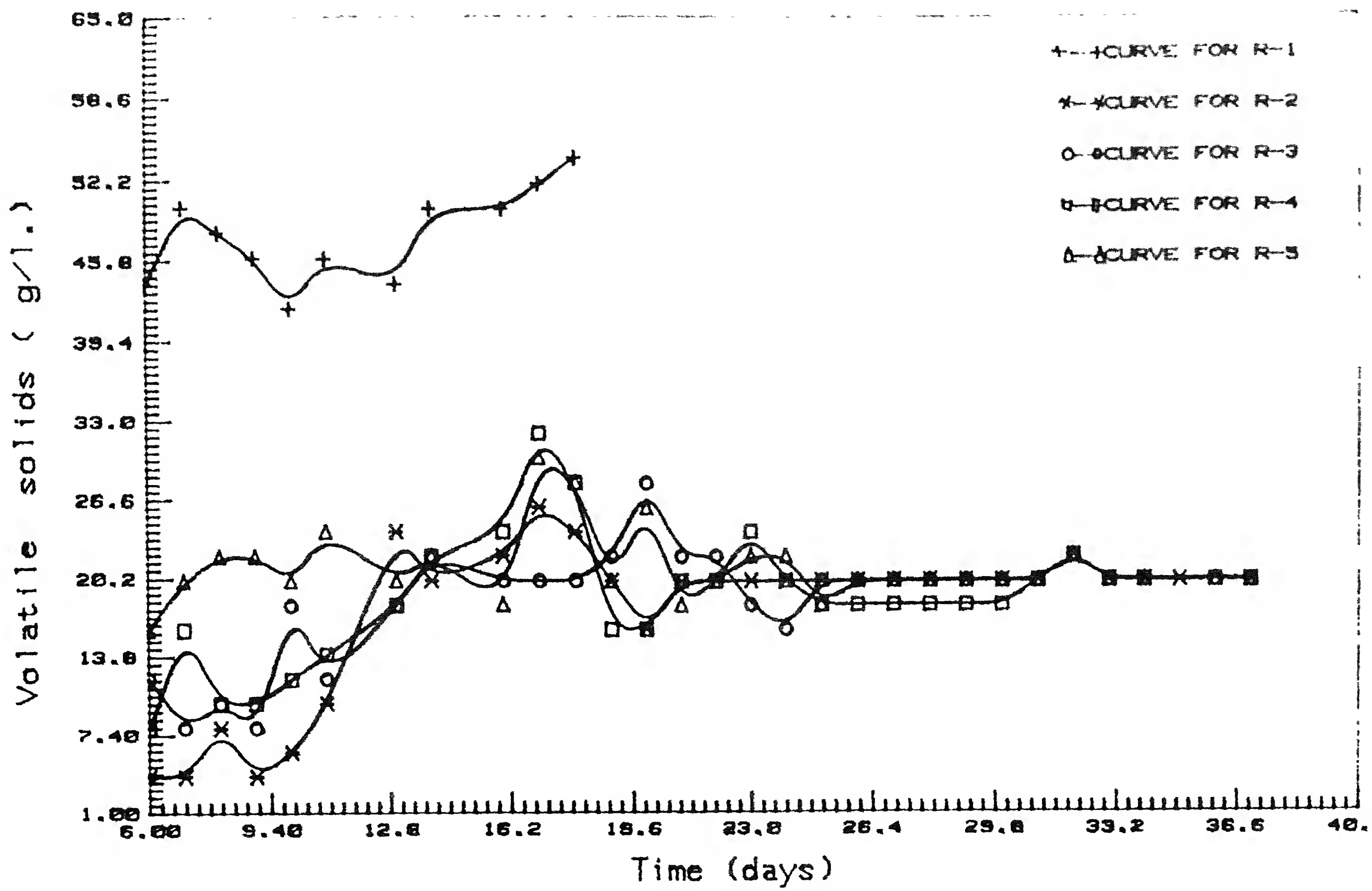


Fig.4.4 Variation of Volatile Solids of Effluent with Time for HRT of 10 Days for 5 Reactors

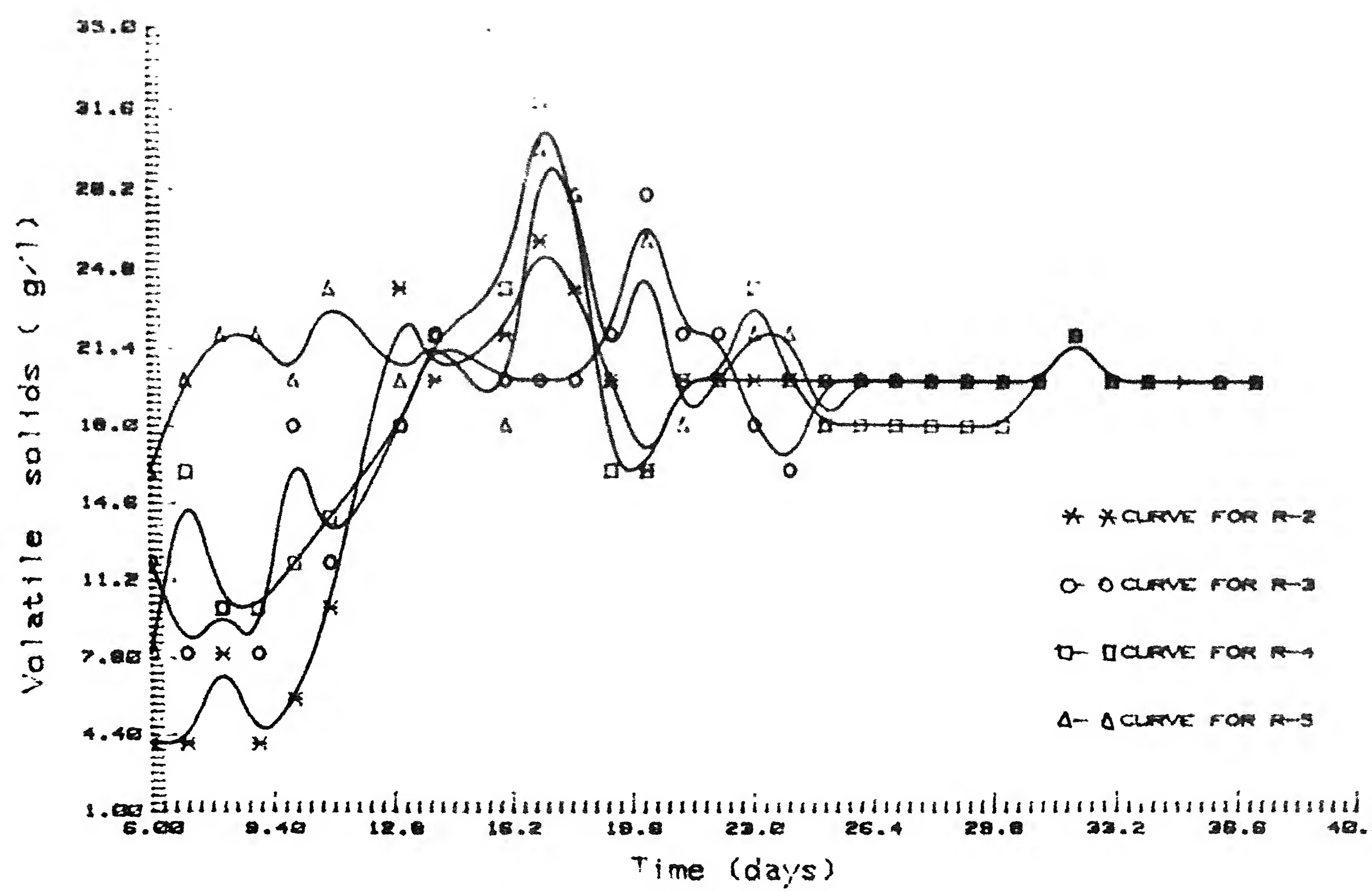


Fig.4.5 Variation of Volatile Solids of Effluent with Time for a HRT of 10 Days for 4 Reactors

Graphstar

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As the gas yield is a representation of the consumption of the VS, it should therefore increase in the beginning and then become constant when the reactor has reached a steady condition. Under this condition, then VS of the influent slurry is consumed and that of the discharged slurry remains constant. The VS consumed is given by

$$\text{VS Consumed}=\left[\frac{V_i \times (VS)_i + (C-V_\ell) \times VS_e}{C} - (VS)_e\right] \times HRT$$

Where:--

$V_i$-- Volume of in fluent

$V_\ell$ -- Volume of effluent

$(VS)_i$-- Volatile solids of influent

$(VS)_e$-- Volatile solids of infflu ent

C -- Capacity of the reactor

HRT--Hydraulic Retention Time considered

**b HRT of three days:--**

The variations of the VS of the discharged slurry for this retention time are shown in Fig. 4.6. The VS data for both the influent and effluent slurries are given in Table 4.2. As for HRT of 10 days, the VS of the discharged slurry in this case also becomes constant under steady state condition.

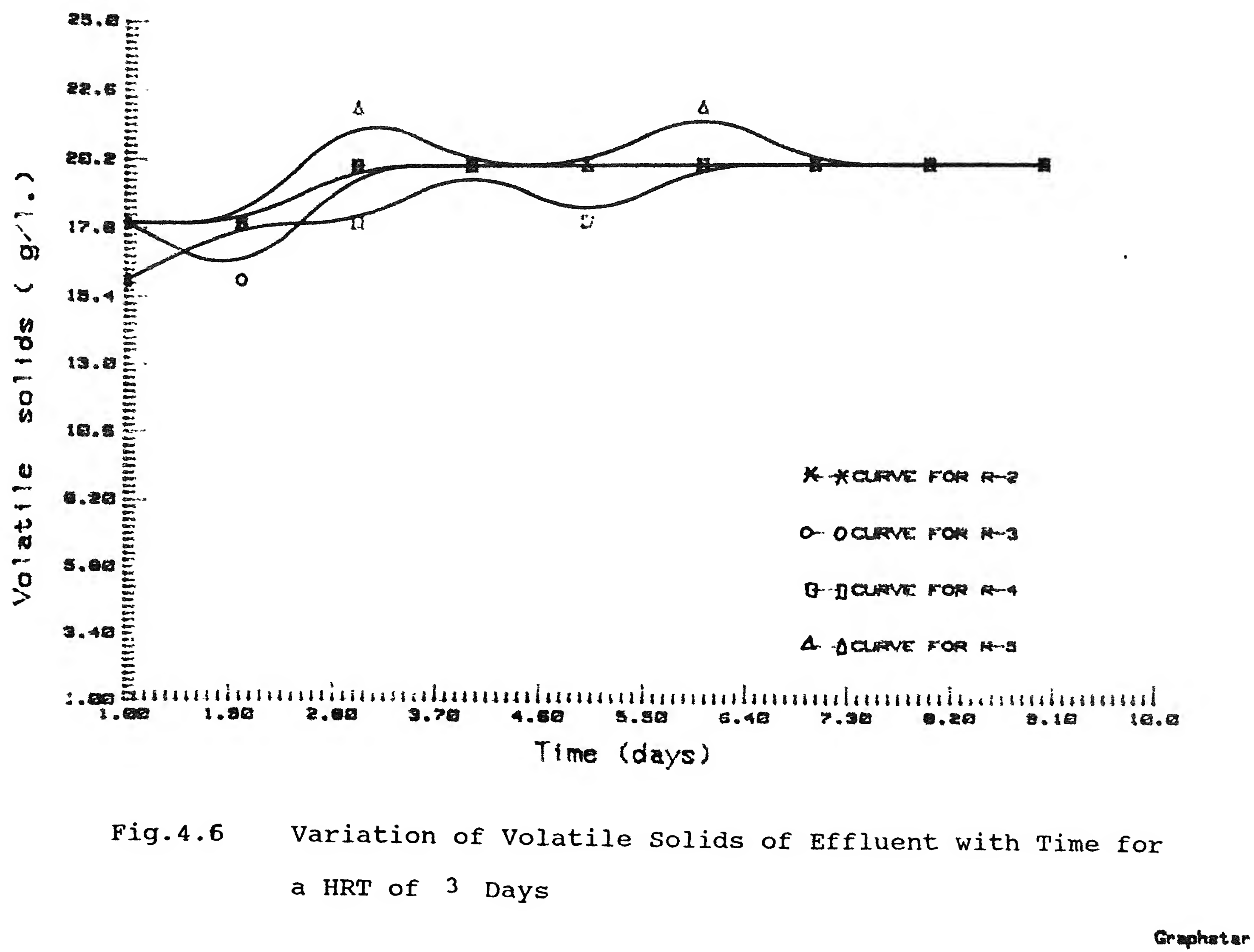


Fig.4.6 Variation of Volatile Solids of Effluent with Time for a HRT of 3 Days

## 4.4 DERIVED RESULTS:--

From the data discussed above, following three types of results were derived.

1.. Gas yield per unit mass of Vs of discharge slurry.

2.. Gas yield per unit mass of VS consumed.

3.. Increased gas yield per unit additional surface area.

**a. HRT of ten days:--**

Fig 4.7 shows the variation of gas yield per unit VS of the discharged slurry with time. Conceptually, the increment in the gas yield decreases the VS value of the discharged slurryand vice versa. The gas yield per unit VS of the discharged slurry is pretty sensitive to the change in either the gas yield or the VS of the discharge, but for the stabilized condition it has to be a constant if the VS of the influent remains constant.

Under steady state conditions, in the present study, the value is maximum for R-3 followed by R-4, R-5 and R-2. The data are listed in Table 4.1. The study showed that the plastic pieces were more effective for microbial attachment than the PVC tubes. Both R-5 and R-2 gave almost the same value.

Fig. 4.8 shows the value of the gas yield per unit mass of the VS consumed. They are also given in Table 4.1. In reality, the gas yield per unit quantity of VS consumed should be same for all the reactors. In the present case, however, owing to the inaccuracy involved in weighing, the gas yield per unit quantity

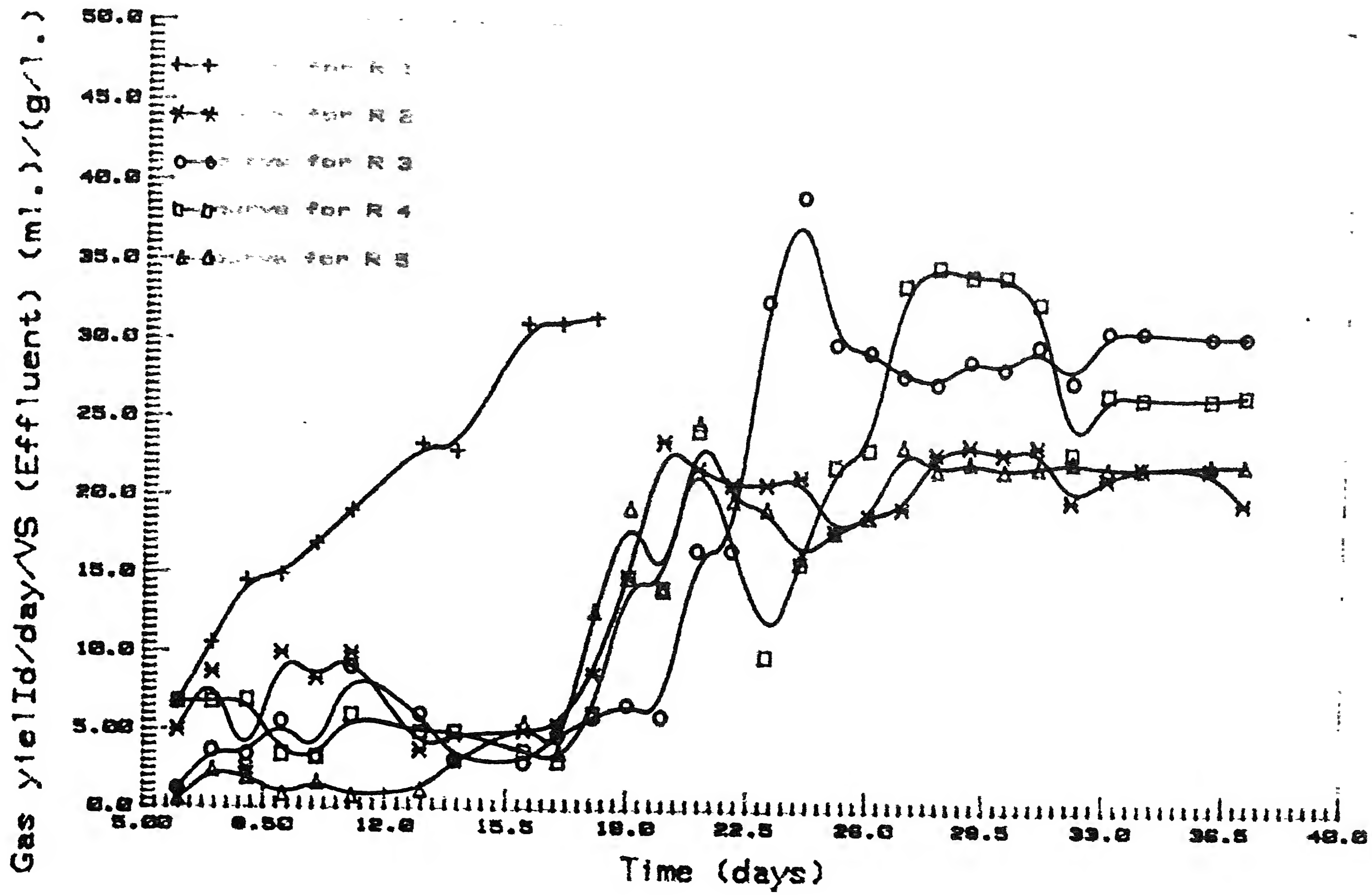


Fig.4.7 Variation of Daily Gas Yield per Unit VS of Effluent with Time for a HRT of 10 Days

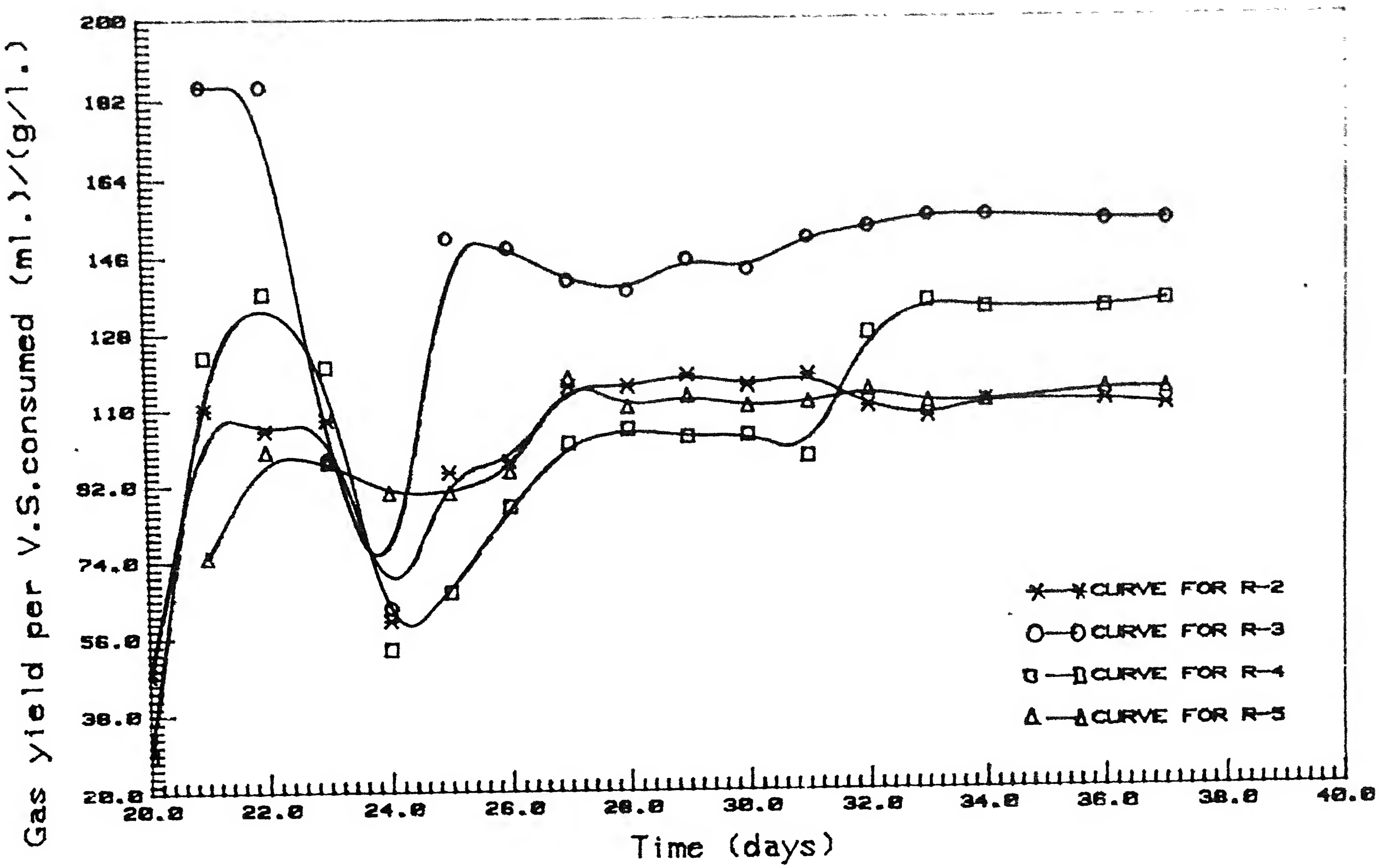


Fig.4.8 Variation of Daily Gas Yield per Unit VS Consumed with Time for a HRT of 10 Days

Graphstar

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of VS consumed was not same for all the reactors as shown in Fig. 4.8.

Fig. 4.9 shows the variation of the increased gas yield per unit additional surface area for the three different media used in the reactors. This increase in the gas yield was calculated by subtracting the gas yield of R-2 (taken as a reference reactor) from the gas yield of the other reactors. This plot actually shows which type of media or packing material is more effective in the steady state. Data for the increased gas yield per unit additional surface area are also given in Table 4.1.

**b. HRT of three days:--**

Fig. 4.10 shows the gas variation of the gas yield per unit mass of the discharge slurry with time. The data are also given in Table 4.2. The results obtained with this retention time are similar to those obtained with HRT of 10 days.

Fig.4.11 shows the variation of the gas yield per unit mass of VS consumed. The data are also given in Table 4.2. Here again the results are similar to those obtained with HRT of 10days.

Fig.4.12 shows the variation of the increased gas yield per unit additional surface area for the three different media in the reactors. The reactor R-4 showed a decreasing trend contrary to that observed for HRT of 10 days. As mentioned before, R-3 had broken and therefore only limited data are reported for this reactor. The reactor R-5 also showed gas yield lower than the

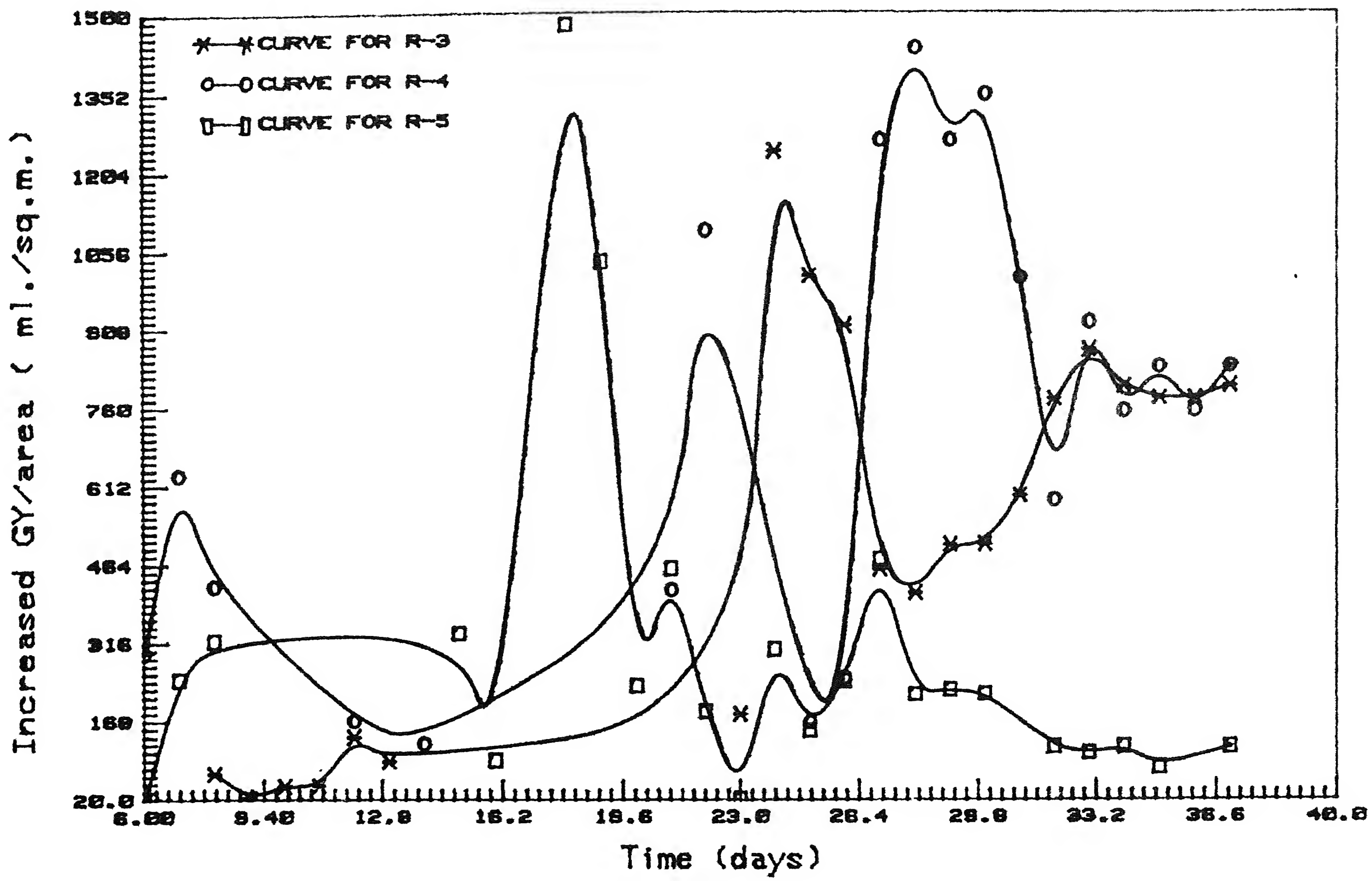


Fig. 4.9 Variation of Daily Increased Gas Yield per Unit Addition Surface Area with Time for a HRT of 10 Days

Graphstar

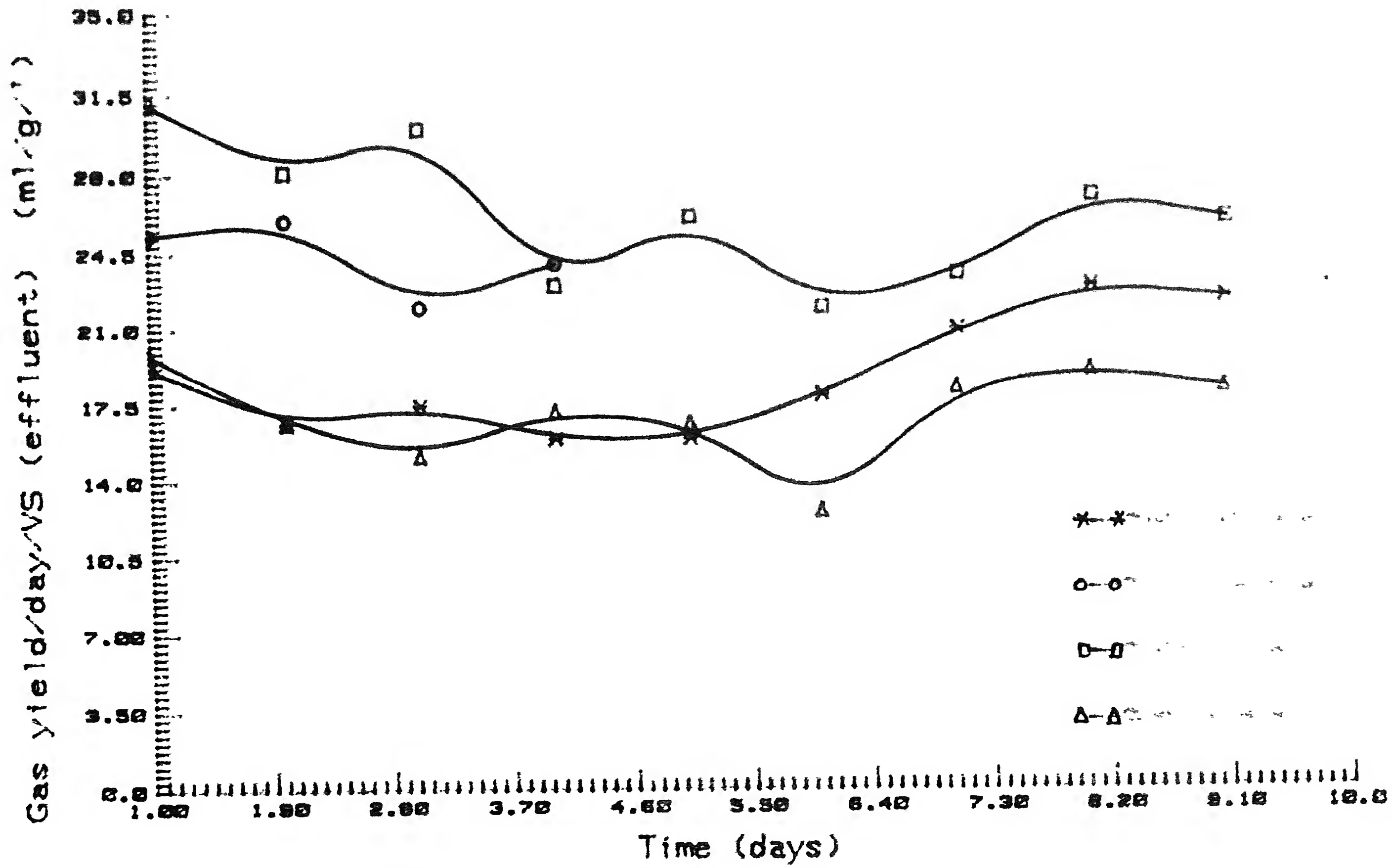


Fig.4.10 Variation of Daily Gas Yield per Unit VS of Effluent with Time for a HRT of 3 Days

Graphstar

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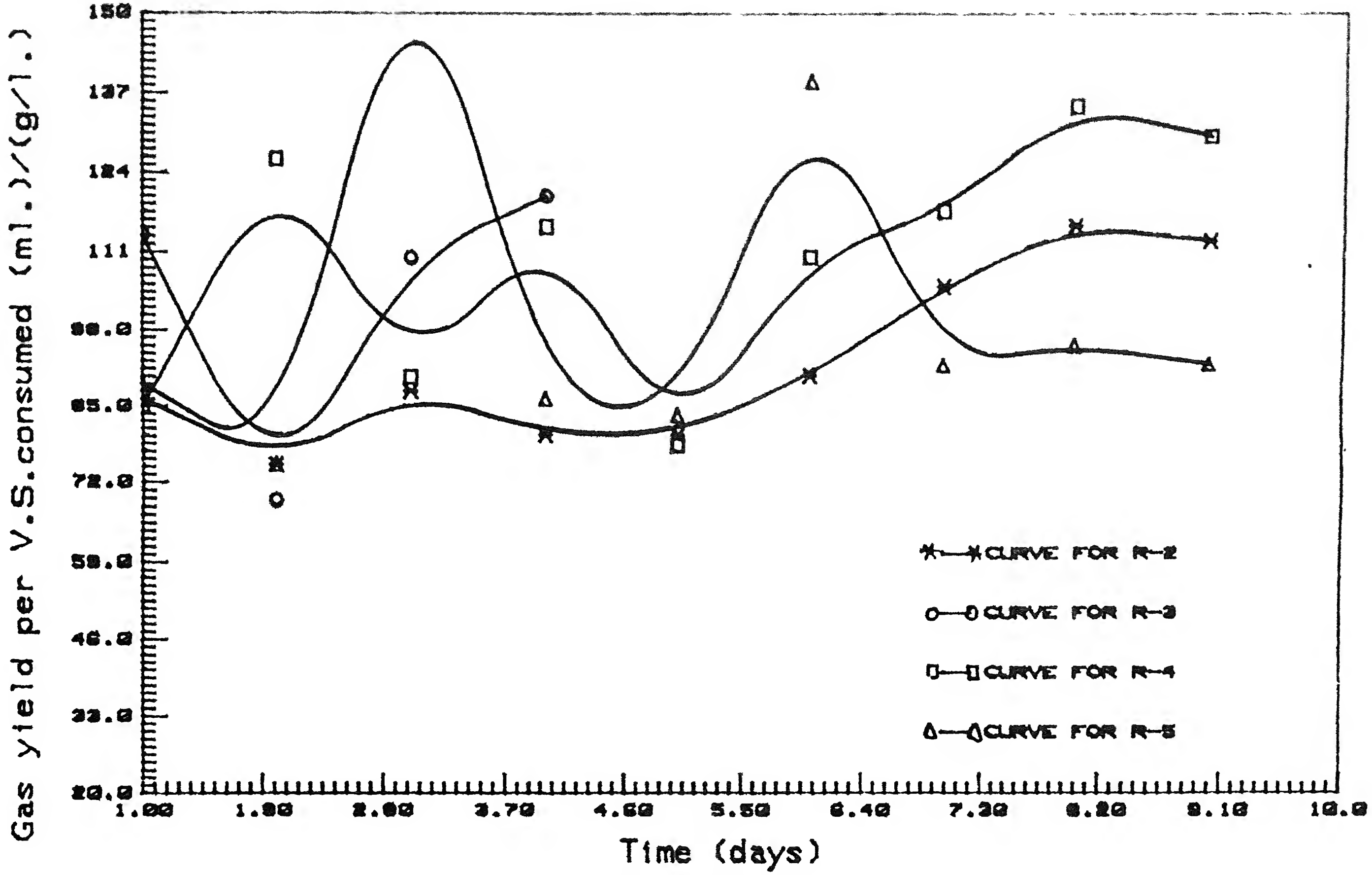


Fig.4.11 Variation of Daily Gas Yield per Unit VS Consumed with Time for a HRT of 3 Days

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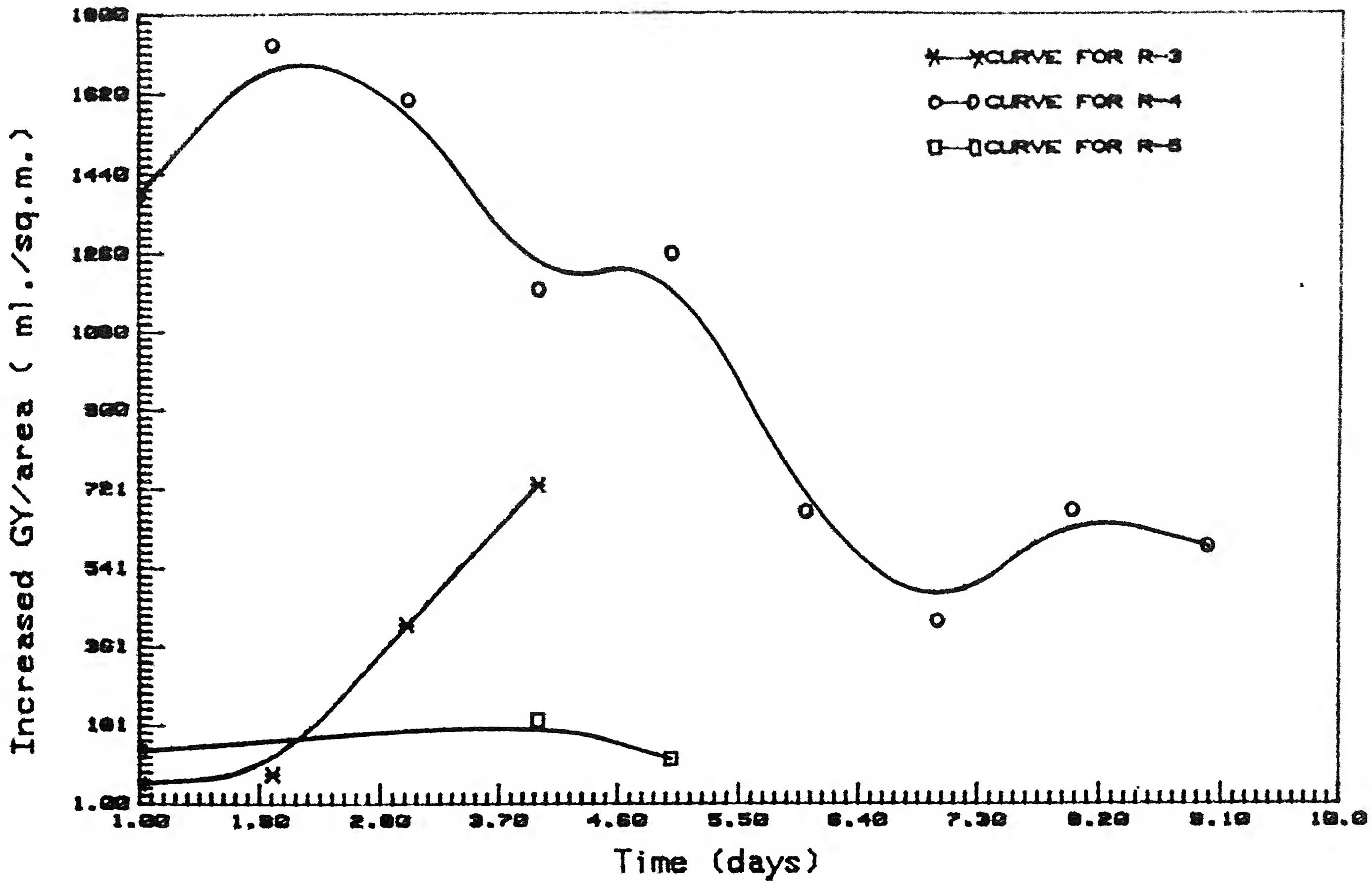


Fig.4.12 Variation of Daily Increased Gas Yield per Unit Addition Surface Area with Time for a HRT of 3 Days

Graphstar

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reference reactor R-2. This nature of the reactor characteristics for this HRT of three days can be attributed to the shock loading of the reactor to which they were subjected when the HRT was changed from ten days to three suddenly. The data are given in table 4.2.

### 4.5 COMPARISON OF THE ADVANCED REACTORS WITH EXISTING BIOGAS PLANT DESIGNS:--

The performance of the advanced reactors R-1 through R-5 has been discussed in the above paragraphs for two values of HRT (10 days and 3 days). In order to make a direct comparison of these reactors with the existing biogas plant designs, one can calculate the gas production rate in l/kg/day from all the reactors and for different values of HRT and compare the same with existing biogas plant designs. Table 4.3 presents these data. It can be seen clearly from the table that the gas production for all the different reactors are much higher compared to that for the existing plant designs. This clearly shows that a reduction in HRT can lead to much higher gas production per unit feed rates. A comparison of the values of the gas production for the different reactors for a given HRT also shows which media is more effective. The plastic pieces which were used as a media in the present study turned out to be the most effective for increasing the gas production. This is followed by the PVC tubes and stone pieces.

It was expected that the gas production per unit feed rate

Table 4.3

Steady Gas Yield Per kg of Cow Dung and Daily Gas Yield Per Feed Rate

| Reactor | Daily feed rate | Daily gas yield | Retention time days | Gas production per kg cow dung (ml/g) OR (l/kg) | Daily gas yield per unit feed rate (ml/g/day) OR (l/kg/day) |
|---|---|---|---|---|---|
| R-1 | 100 g | 1700 ml | 10 | 17.00 | 1.70 |
| R-2 | 33.3 g | 440 ml | 10 | 13.2 | 1.32 |
| R-3 | 33.3 g | 610 ml | 10 | 18.6 | 1.68 |
| R-4 | 33.3 g | 540 ml | 10 | 16.2 | 1.62 |
| R-5 | 30.0 g | 410 ml | 10 | 13.67 | 1.37 |
| R-2 | 111 g | 440 ml | 3 | 3.96 | 1.32 |
| R-4 | 111 g | 520 ml | 3 | 4.68 | 1.56 |
| R-5 | 100 g | 340 ml | 3 | 3.40 | 1.13 |
| TERI Mark III | 50 kg | 2 $m^3$ | 50 | 40.0 | 0.8 |
| TERI Mark I | 250 kg | 10 $m^3$ | 50 | 40.0 | 0.8 |
| JANATA Model | 50 kg | 2 $m^3$ | 55 | 40.0 | 0.73 |
| DEENBANDHU Model | 50 kg | 2 $m^3$ | 40 | 40.0 | 1.00 |
| KVIC Model | 50 kg | 2 cu.m. | 50 | 40.0 | 0.8 |

for the ART of 3 days would be higher than those for HRT of 10 days, but this is not observed from the table. In fact, there is a decrease in the gas production. This decrease is attributed to the shock loading of the reactors due to sudden reduction in HRT from 10 days to 3 days.

## 4.6 BIOGAS ANALYSIS:--

A sample of the biogas collected from each of the reactors was analyzed by two different methods namely by passing through a 4N KOH solution and also using a Gas Chromatograph. The results are given in Table 4.4. A variation in the numerical values obtained by different methods is because of the accuracy of the method used. It can be seen from the table that the methane content in the gas is different for different packing media. It is highest for the plastic media followed by that for the PVC tubes and stone pieces. Evidently the plastic media was the best of the three, but it was not very different from to the PVC tubes. The stone media showed results similar to those for the suspended slurry.

## 4.7 CHEMICAL OXYGEN DEMAND:--

The COD values of the influent and effluent were determined on a particular day to find the COD utilized per day. Knowing the gas yield on that particular day, one could easily determine the gas yield per unit mass of the COD utilized. Table 4.5 shows the approximate values of the COD for the influent and effluent. More

Table 4.4

Biogas Analysis for HRT of Ten Days

| Method of Analysis | Main Constituents | REACTORS PERECENTAGE | | | |
|---|---|---|---|---|---|
| | | R-2 | R-3 | R-4 | R-5 |
| Biogas by passing through 4N KOH solution and measuring gas without $CO_2$ | $CH_4$ + other gases ( $H_2S$, $H_2$, $N_2$ etc.) | 56.82 | 64.23 | 62.85 | 58.82 |
| | $CO_2$ | 43.18 | 35.77 | 37.15 | 41.18 |
| Gas Chromatography | $CH_4$ | 56.89 | 64.24 | 63.94 | 57.29 |
| | $CO_2$ | 43.11 | 35.76 | 36.06 | 42.71 |

Table 4.5

COD Analysis Only for One Day for 10 Days Retention Time Set

| DATE | Influent OR Effluent | COD Values in (mg/l) | Respective Gas Yield in ml/21/day | Utilized COD per day {$COD_{inf}$ − $COD$}$_{efl}$ (mg/l/day) | Gas Yield per Unit COD utilized (ml/g) |
|---|---|---|---|---|---|
| 17..01..94 | Influent | 22033.9 | | | |
| | R-2 | 11864.4 | 440 | 10169.5 | 216 |
| | R-3 | 8476.6 | 610 | 13557.3 | 225 |
| | R-4 | 11299.4 | 510 | 10734.5 | 238 |
| | R-5 | 11864.4 | 410 | 10169.5 | 224 |

** These figures are negative which don't have any physical significance hence need not to show these values in the Tables 4.1 & 4.2.

* Measurement cauld not available because of the nou availability of the equipment on the time.

-- Measurements cauld not possible because of the experimental problems

gas yield refers to a higher COD which actually will mean a lower value of the COD of the discharged slurry. The gas yield per unit mass of COD utilized has to be approximately constant.

## 4.8 CONCLUSIONS:--

Based upon the experimental data and results derived from the present study, following conclusions are made.

(1).. For the same gas yield, Hydraulic Retention Time (HRT) of a biogas reactor decreases if the surface area inside the reactor for the attachment of the microbes, increases.

(2).. For the same HRT, gas yield from a reactor and methane content in it increase if the surface area provided for the microbial attachment increases.

(3).. Daily gas yield per unit feed rate increase by reducing HRT and increasing the surface area for the attachment of the microbes.

(4).. Decrease in the slurry concentration decreases the gas yield.

(5).. Sudden increase in the feed rate due to a reduction in HRT causes reduction in the gas yield due to shock loading.

P.S. *It may be noted that for the derived results for reactor ive (R-5), gas yield was considered 11 % more than the actual gas ield . This was because of the capacity of R-5 was 1.8 litre, but for he other reactors it was 2 litres. In order to make the results quivalent to the other reactors actual gas yield was multiplied by 1.11.*

## 4.9. SUGGESTIONS FOR THE FUTURE RESEARCH:--

1. Experiments should be conducted with different retention times preferably of less than 10 days so that an optimum retention time can be found.
2. Experiments may be carried out with other materials as the packing media in some suitable arrangement so that a large surface area becomes available for the microbial attachment and yet it is possible to stir the slurry without any clogging.
3. Experiments with slurry of cow dung and water in the ratio of 1:1 may be carried out on relatively big size reactors with the objective of getting higher gas yield and studying the effect of retention time. The effect of increasing the surface area for the microbial attachment with 1:1 slurry should also be studied.
4. Besides carrying out the studies under controlled environmental conditions of temperature, pH value etc., they should also be carried out at ambient temperature in different seasons.

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